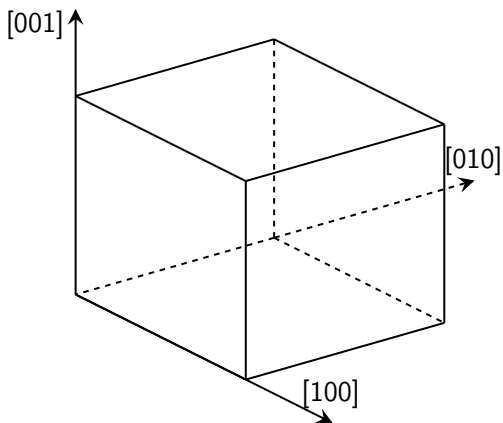


Plasticity at the crack tip in single crystals

Sylvain Flourirot, Samuel Forest

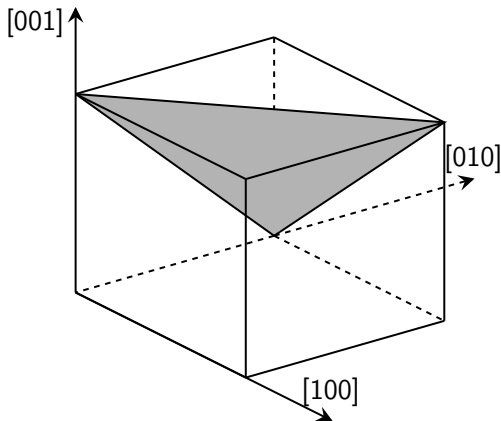
Centre des Matériaux/UMR 7633
Ecole des Mines de Paris/CNRS
Samuel.Forest@ensmp.fr

Continuum crystal plasticity – Deformation mechanisms



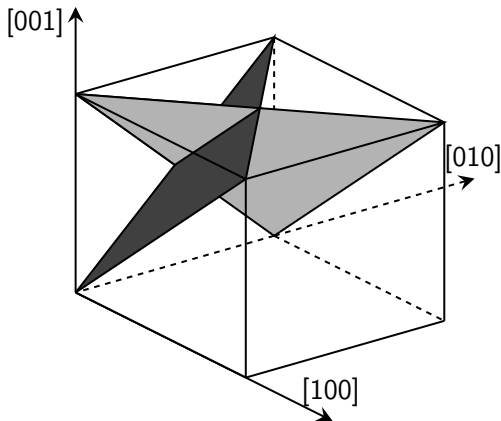
Continuum crystal plasticity – Deformation mechanisms

Slip systems: $\{111\} \langle 110 \rangle$



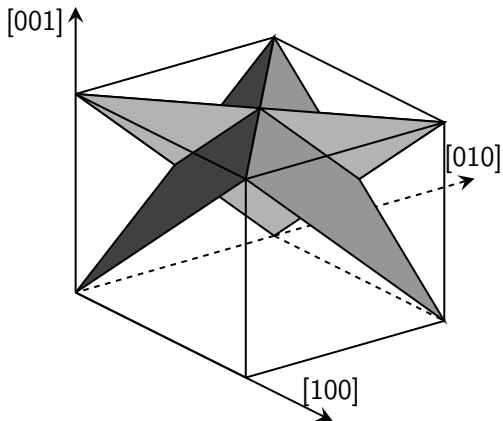
Continuum crystal plasticity – Deformation mechanisms

Slip systems: $\{111\} \langle 110 \rangle$



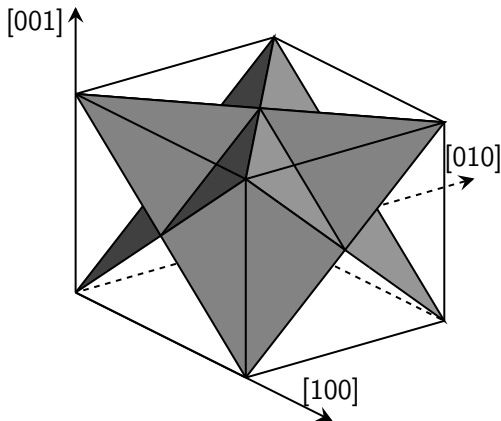
Continuum crystal plasticity – Deformation mechanisms

Slip systems: $\{111\} \langle 110 \rangle$



Continuum crystal plasticity – Deformation mechanisms

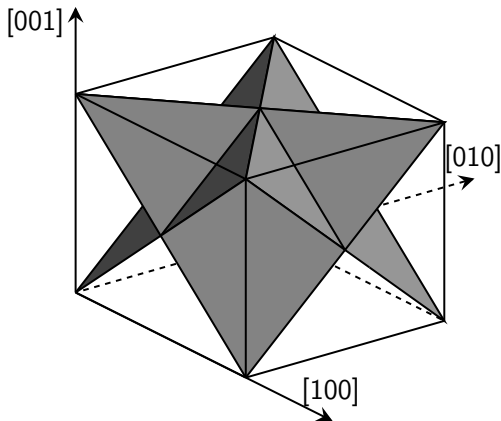
Slip systems: $\{111\} \langle 110 \rangle$



Continuum crystal plasticity – Deformation mechanisms

Slip systems: $\{111\} \langle 110 \rangle$

Schmid Law : $\tau^s = \underline{\sigma} : \underline{\mathbf{m}}^s = \tau_c$



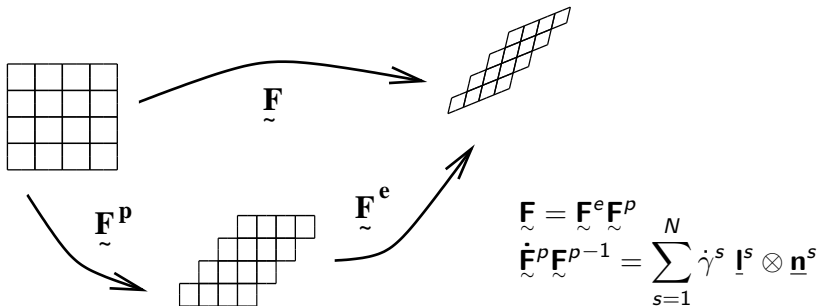
$$\dot{\underline{\epsilon}}^p = \sum_{s=1}^{12} \underline{\mathbf{m}}^s \dot{\gamma}^s$$

$$\underline{\mathbf{m}}^s = \frac{1}{2} (\underline{\mathbf{l}}^s \otimes \underline{\mathbf{n}}^s + \underline{\mathbf{n}}^s \otimes \underline{\mathbf{l}}^s)$$

$\underline{\mathbf{n}}^s$: normal to the slip plane

$\underline{\mathbf{l}}^s$: slip direction

Lattice rotation



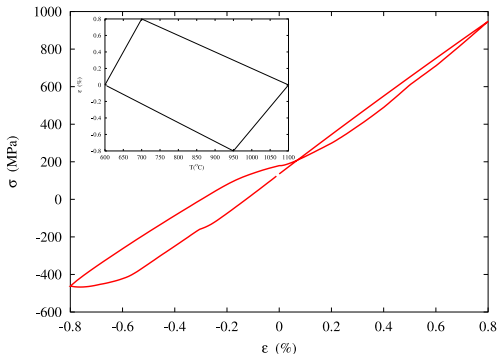
Lattice rotation:

$$\phi = \arccos \left(\frac{\text{tr}(\tilde{\mathbf{R}}) - 1}{2} \right)$$

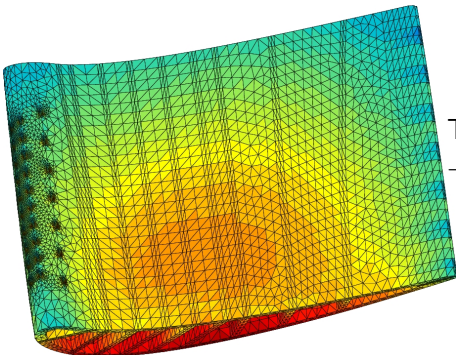
with $\tilde{\mathbf{F}}^e = \tilde{\mathbf{R}} \tilde{\mathbf{U}}$

Validity of the continuum approach

- Tension-LCF
- Torsion
- Anisothermal Fatigue
- Structures



Turbine blade
→ Single crystal
nickel–base superalloy



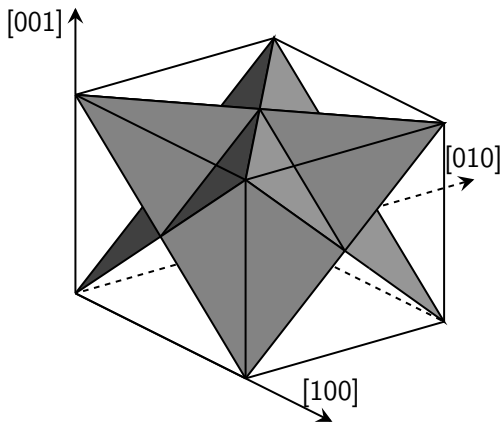
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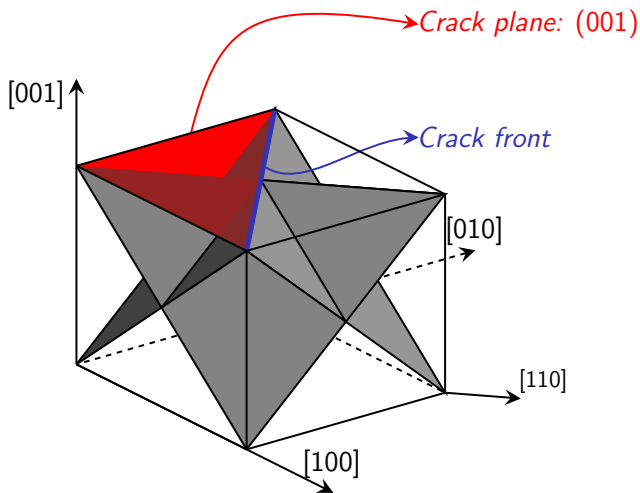
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Effective slip systems



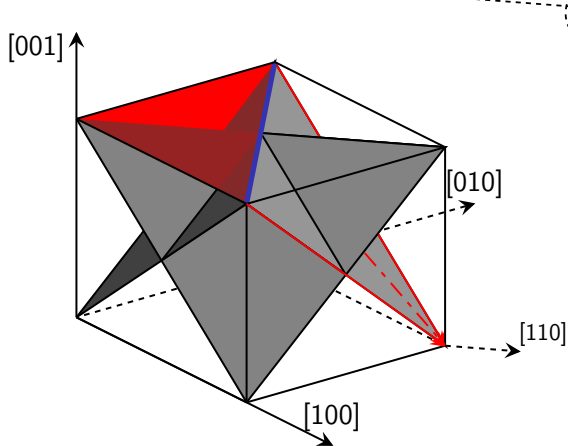
Effective slip systems



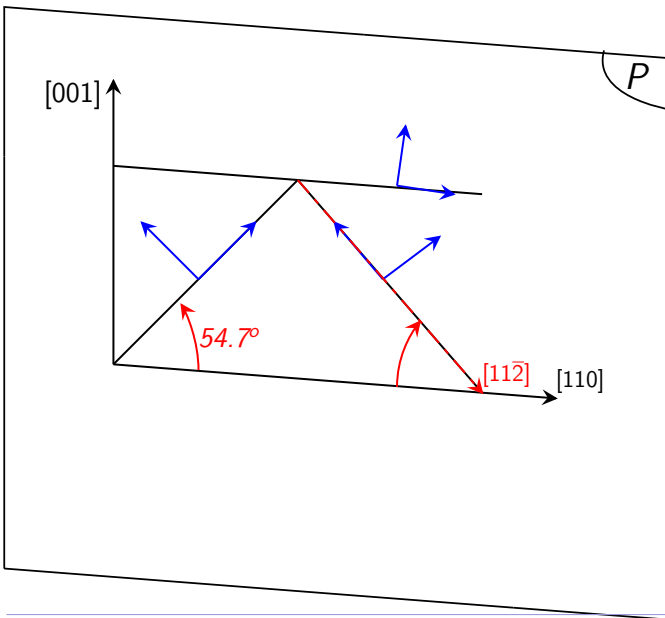
Notation : $\gamma(\text{plane})[\text{direction de propagation}]$

$\gamma(001)[110] \implies \text{Orientation } S$

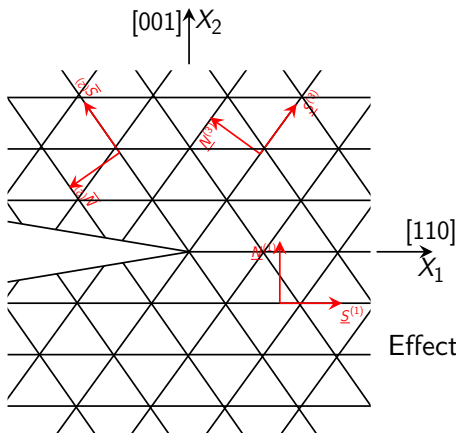
Effective slip systems



Effective slip systems



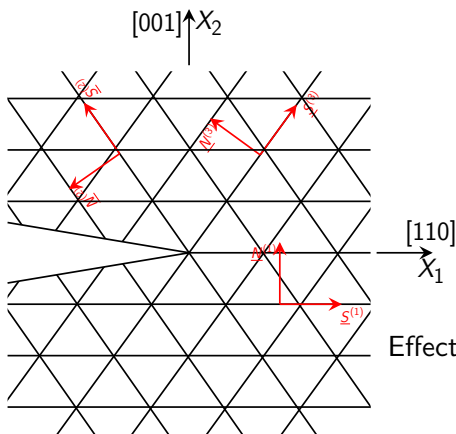
Effective slip systems



n^i	l^i	$N^{(s)}$	$S^{(s)}$	
$(\bar{1}11)$	$[110]$	(001)	$[110]$	(1)
$(1\bar{1}1)$	$[110]$			
(111)	$[\bar{1}01]$	(111)	$[\bar{1}\bar{1}2]$	(2)
(111)	$[0\bar{1}1]$			
$(11\bar{1})$	$[101]$	$(11\bar{1})$	$[112]$	(3)
$(11\bar{1})$	$[011]$			

Effective Schmid law: $\underline{S}^{(s)} \cdot \underline{\sigma} \cdot \underline{N}^{(s)} = \beta^{(s)} \tau_c$

Effective slip systems

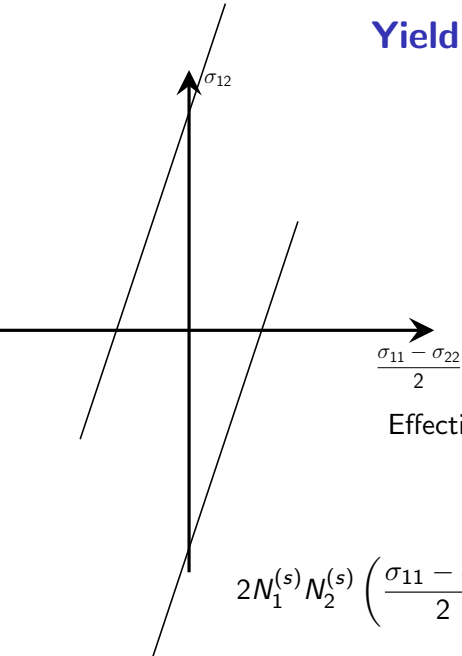


n^i	l^i	$N^{(s)}$	$S^{(s)}$	
$(\bar{1}11)$	$[110]$	$\left. \begin{array}{l} (001)[110] \end{array} \right\}$	$(001)[110]$	(1)
$(1\bar{1}1)$	$[110]$			
(111)	$[\bar{1}01]$	$\left. \begin{array}{l} (111)[\bar{1}12] \end{array} \right\}$	$(111)[\bar{1}12]$	(2)
(111)	$[0\bar{1}1]$			
$(11\bar{1})$	$[101]$	$\left. \begin{array}{l} (11\bar{1})[112] \end{array} \right\}$	$(11\bar{1})[112]$	(3)
$(11\bar{1})$	$[011]$			

Effective Schmid law: $\underline{S}^{(s)} \cdot \underline{\sigma} \cdot \underline{N}^{(s)} = \beta^{(s)} \tau_c$

$$2N_1^{(s)} N_2^{(s)} \left(\frac{\sigma_{11} - \sigma_{22}}{2} \right) + \left(N_2^{(s)^2} - N_1^{(s)^2} \right) \sigma_{12} = \beta^{(s)} \tau$$

Yield surface

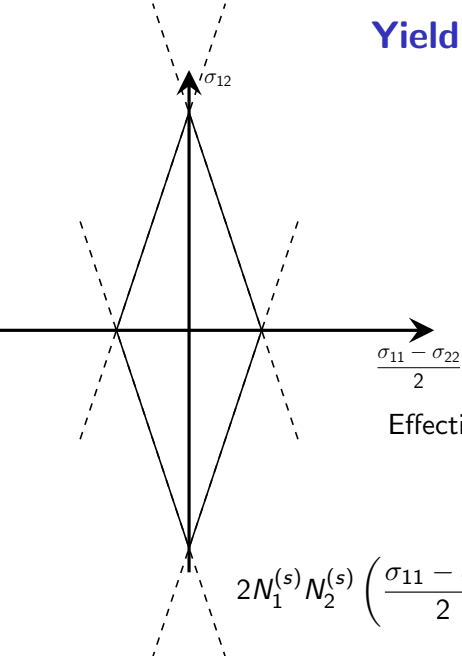


n^i	l^i	$N^{(s)}$	$S^{(s)}$
$(\bar{1}11)[110]$	}	$(001)[110]$	(1)
$(1\bar{1}1)[110]$			
$(111)[\bar{1}01]$	}	$(111)[\bar{1}\bar{1}2]$	(2)
$(111)[0\bar{1}1]$			
$(11\bar{1})[101]$	}	$(11\bar{1})[112]$	(3)
$(11\bar{1})[011]$			

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Yield surface

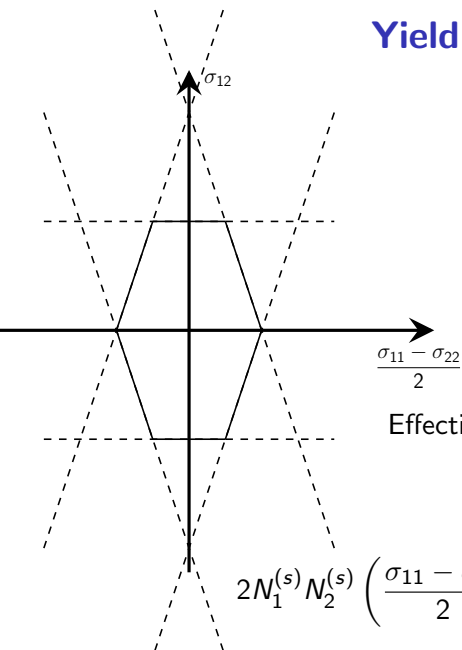


n^i	l^i	$N^{(s)}$	$S^{(s)}$
$(\bar{1}11)[110]$	}	$(001)[110]$	(1)
$(1\bar{1}1)[110]$			
$(111)[\bar{1}01]$	}	$(111)[\bar{1}\bar{1}2]$	(2)
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Yield surface

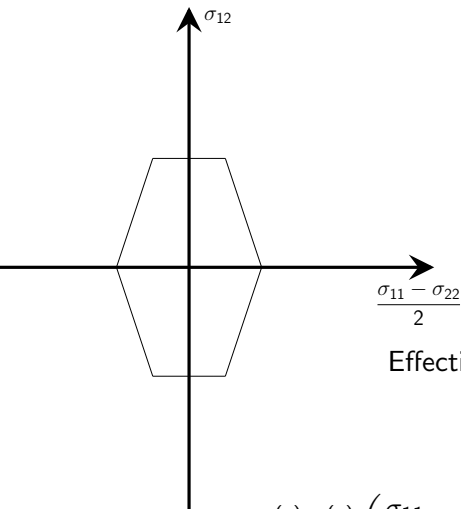


n^i	l^i	$N^{(s)}$	$S^{(s)}$
$(\bar{1}11)[110]$	}	$(001)[110]$	(1)
$(1\bar{1}1)[110]$			
$(111)[\bar{1}01]$	}	$(111)[\bar{1}\bar{1}2]$	(2)
$(111)[0\bar{1}1]$			
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$(11\bar{1})[011]$			

Effective Schmid law: $\underline{\mathbf{S}}^{(s)} \cdot \underline{\boldsymbol{\sigma}} \cdot \underline{\mathbf{N}}^{(s)} = \beta^{(s)} \tau_c$

$$2N_1^{(s)}N_2^{(s)}\left(\frac{\sigma_{11}-\sigma_{22}}{2}\right) + \left(N_2^{(s)^2} - N_1^{(s)^2}\right)\sigma_{12} = \beta^{(s)}\tau$$

Yield surface



n^i	l^i	$N^{(s)}$	$S^{(s)}$
$(\bar{1}11)[110]$	}	$(001)[110]$	(1)
$(1\bar{1}1)[110]$			
$(111)[\bar{1}01]$	}	$(111)[\bar{1}\bar{1}2]$	(2)
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Effective Schmid law: $\underline{\mathbf{S}}^{(s)} \cdot \underline{\boldsymbol{\sigma}} \cdot \underline{\mathbf{N}}^{(s)} = \beta^{(s)} \tau_c$

$$2N_1^{(s)} N_2^{(s)} \left(\frac{\sigma_{11} - \sigma_{22}}{2} \right) + \left(N_2^{(s)2} - N_1^{(s)2} \right) \sigma_{12} = \beta^{(s)} \tau$$

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Field equation for balance of momentum

$$\operatorname{div} \boldsymbol{\sigma} = \frac{\partial \sigma_{ij}}{\partial x_i} = 0$$

Cartesian stress components as functions of cylindrical coordinates (r, θ) :

$$\begin{cases} x_1 = r \cos \theta \\ x_2 = r \sin \theta \end{cases}$$

$$\operatorname{div} \boldsymbol{\sigma} = \frac{\partial \sigma_{ij}}{\partial r} \frac{\partial r}{\partial x_i} + \frac{\partial \sigma_{ij}}{\partial \theta} \frac{\partial \theta}{\partial x_i} = 0$$

$$\begin{cases} -\lim_{r \rightarrow 0} \left(\frac{\partial \sigma_{11}}{\partial \theta} \right) \sin \theta + \lim_{r \rightarrow 0} \left(\frac{\partial \sigma_{12}}{\partial \theta} \right) \cos \theta = 0 \\ -\lim_{r \rightarrow 0} \left(\frac{\partial \sigma_{12}}{\partial \theta} \right) \sin \theta + \lim_{r \rightarrow 0} \left(\frac{\partial \sigma_{22}}{\partial \theta} \right) \cos \theta = 0 \end{cases}$$

Field equation for balance of momentum

$$\frac{\partial \sigma_{12}}{\partial \theta} = - \frac{N_1^{(s)} N_2^{(s)}}{N_2^{(s)2} - N_1^{(s)2}} \frac{\partial (\sigma_{11} - \sigma_{22})}{\partial \theta}$$

$$\begin{cases} a = \lim_{r \rightarrow 0} \frac{\partial (\sigma_{11} + \sigma_{22})}{\partial \theta} \\ b = \lim_{r \rightarrow 0} \frac{\partial (\sigma_{11} - \sigma_{22})}{\partial \theta} \end{cases}$$

$$\rightarrow \begin{cases} a \sin \theta + b \left(2 \frac{N_1^{(s)} N_2^{(s)}}{N_2^{(s)} - N_1^{(s)}} \cos \theta + \sin \theta \right) = 0 \\ a \sin \theta + b \left(2 \frac{N_1^{(s)} N_2^{(s)}}{N_2^{(s)} - N_1^{(s)}} \sin \theta + \cos \theta \right) = 0 \end{cases}$$

$$\Rightarrow a = b = 0 \Rightarrow \begin{cases} \lim_{r \rightarrow 0} \frac{\partial \sigma_{11}}{\partial \theta} = 0 \\ \lim_{r \rightarrow 0} \frac{\partial \sigma_{22}}{\partial \theta} = 0 \\ \lim_{r \rightarrow 0} \frac{\partial \sigma_{12}}{\partial \theta} = 0 \end{cases}$$

Cartesian stress components
constant in sectors

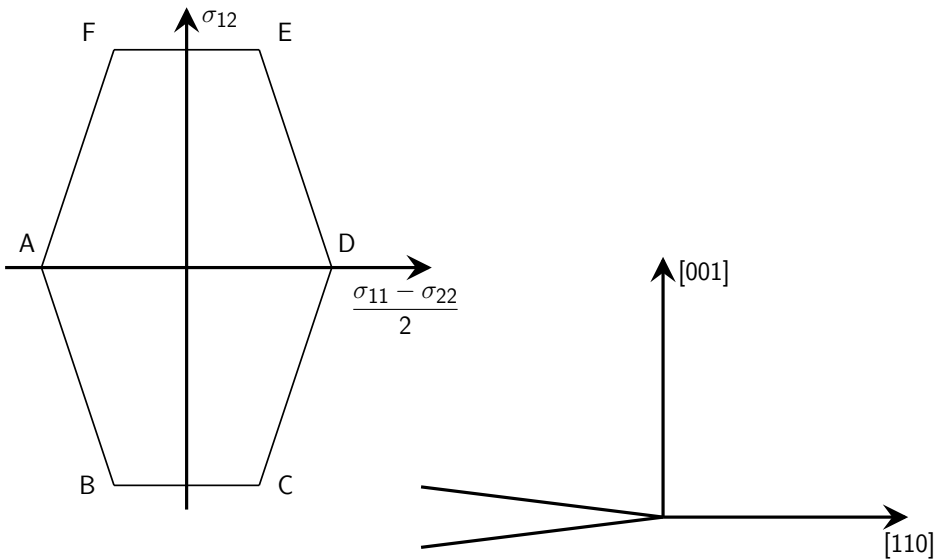
Field equation for balance of momentum

Discontinuity conditions: $\tan 2\theta = 2 \frac{N_1^{(s)} N_2^{(s)}}{N_2^{(s)2} - N_1^{(s)2}}$

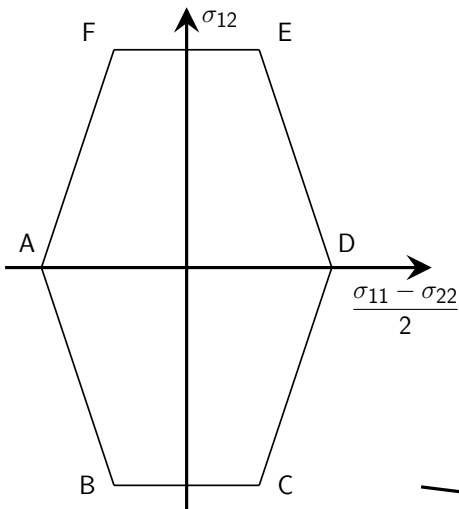
\Rightarrow 6 possible values:

$$\theta = \begin{cases} 0^\circ \\ 90^\circ \end{cases} \quad \begin{cases} 35.26^\circ \\ 125.26^\circ \end{cases} \quad \begin{cases} 54.74^\circ \\ 144.74^\circ \end{cases}$$

Construction of a solution of the crack problem

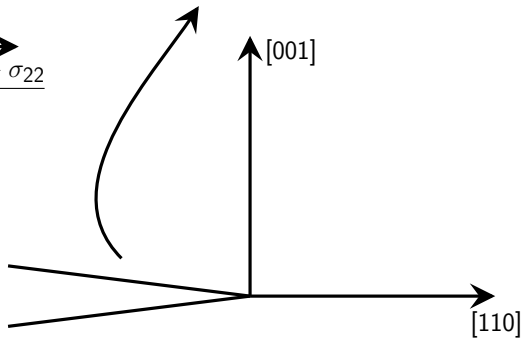


Construction of a solution of the crack problem

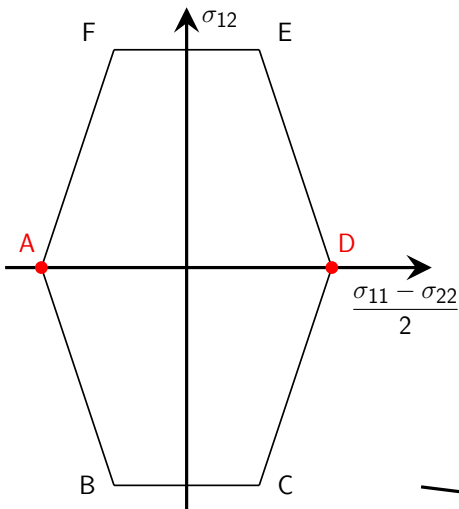


Boundary conditions

- $\sigma_{12} = 0$
- $\sigma_{22} = 0$
- $\sigma_{11} = ??$

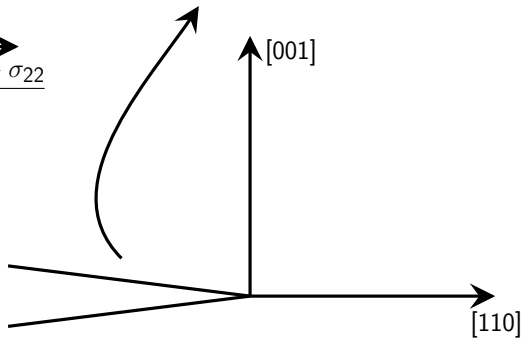


Construction of a solution of the crack problem

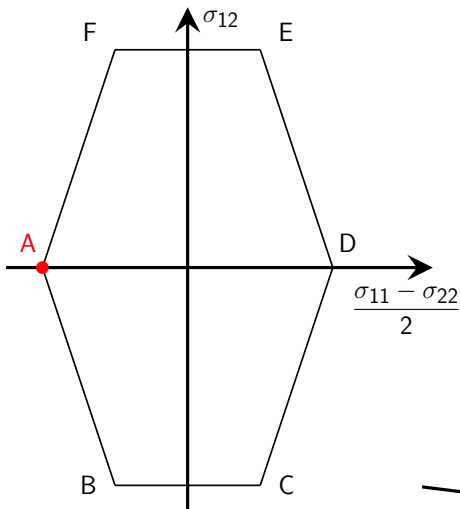


Boundary conditions

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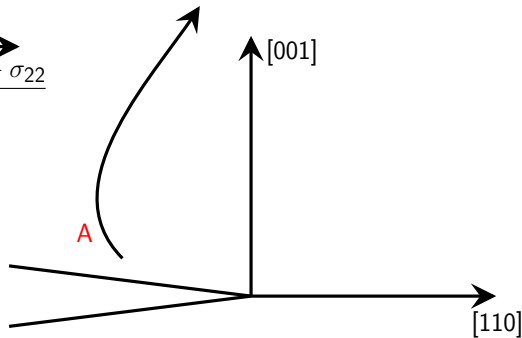


Construction of a solution of the crack problem

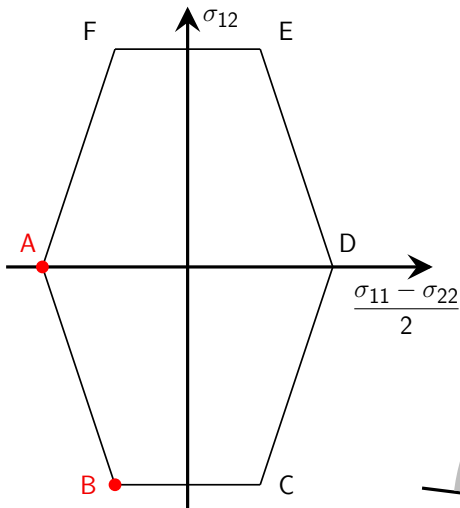


Boundary conditions

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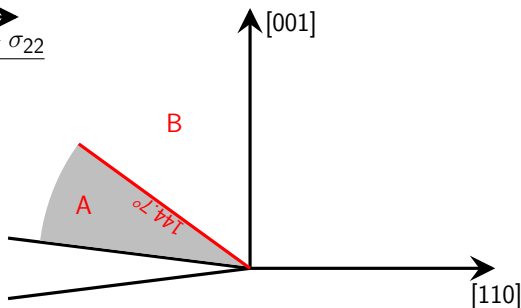


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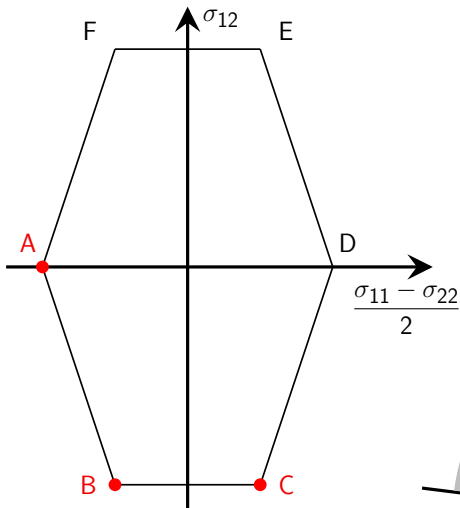


solution

- $\sigma_{12}^A = 0$
- $\sigma_{22}^A = 0$
- $\sigma_{11}^A = -\sqrt{6}\tau_{oc}$

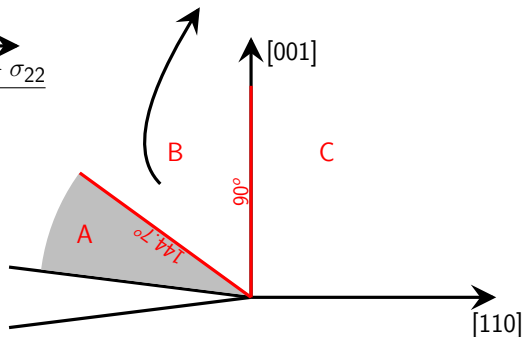


Construction of a solution of the crack problem

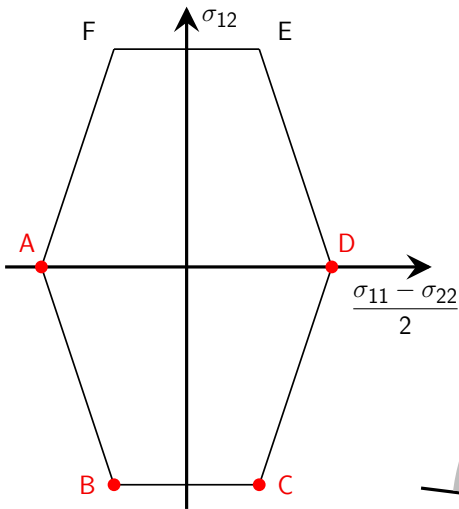


solution

- $\sigma_{12}^B = -\sqrt{3}\tau_{oc}$
- $\sigma_{22}^B = \sqrt{3/2}\tau_{oc}$
- $\sigma_{11}^B = 0$

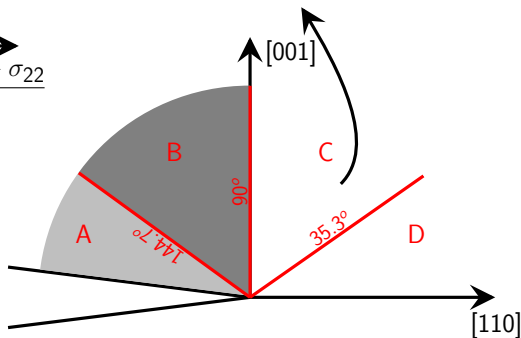


Construction of a solution of the crack problem

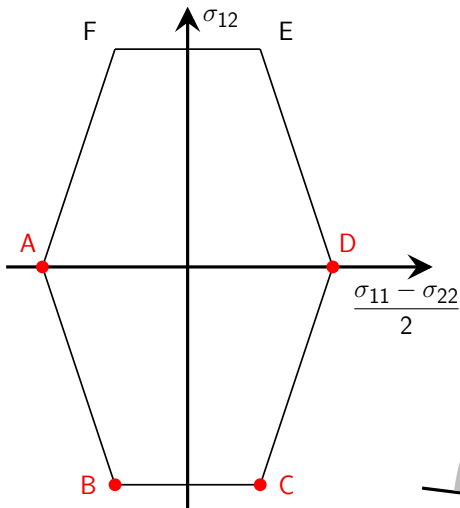


solution

- $\sigma_{12}^C = -\sqrt{3}\tau_{oc}$
- $\sigma_{22}^C = -\sqrt{3/2}\tau_{oc}$
- $\sigma_{11}^C = 0$

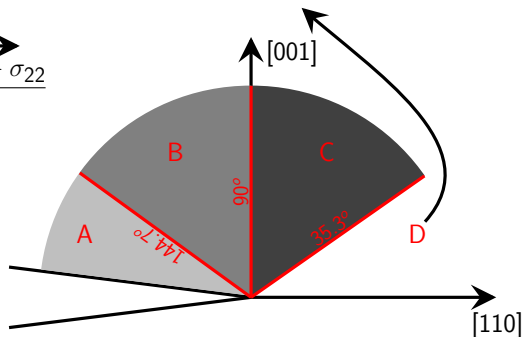


Construction of a solution of the crack problem

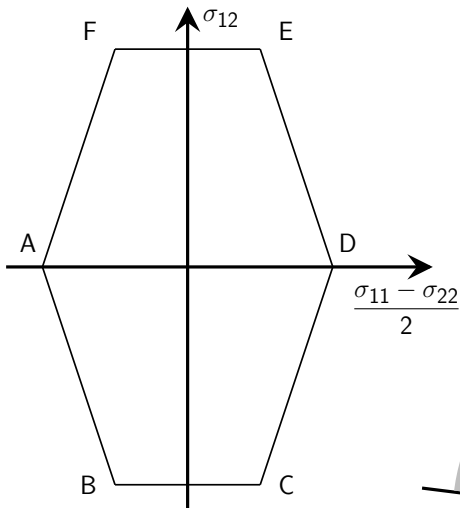


solution

- $\sigma_{12}^D = 0$
- $\sigma_{22}^D = 0$
- $\sigma_{11}^D = \sqrt{6}\tau_{oc}$

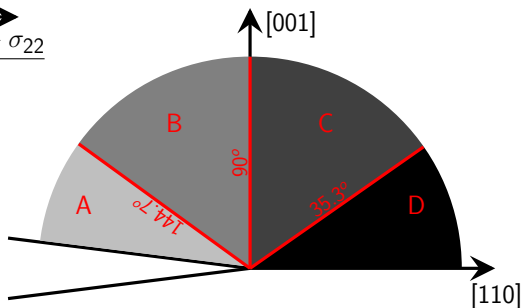


Construction of a solution of the crack problem

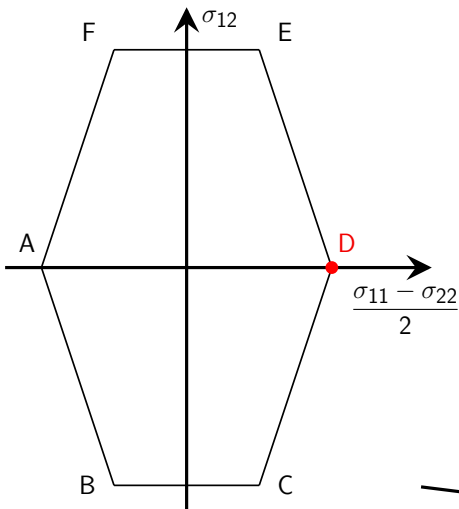


solution

- $\sigma_{12}^D = 0$
- $\sigma_{22}^D = 0$ not acceptable !!
- $\sigma_{11}^D = \sqrt{6}\tau_{oc}$

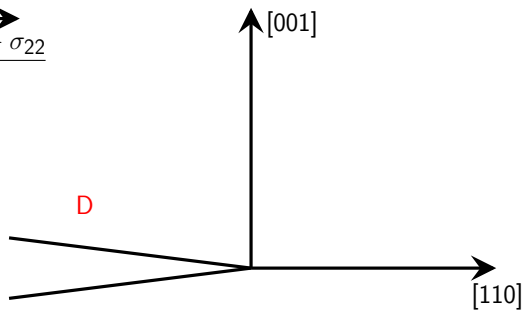


Construction of a solution of the crack problem

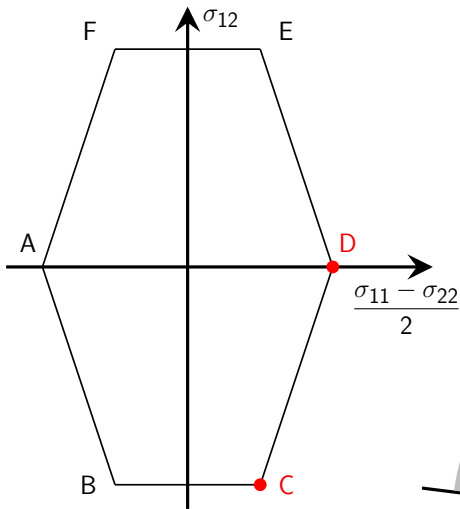


Boundary conditions

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- $\sigma_{11} = ??$

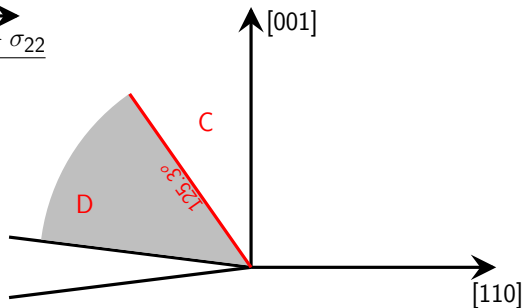


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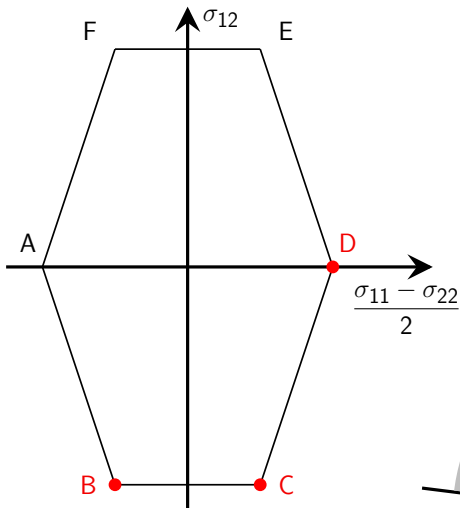


solution

- $\sigma_{12}^D = 0$
- $\sigma_{22}^D = 0$
- $\sigma_{11}^D = \sqrt{6}\tau_{oc}$

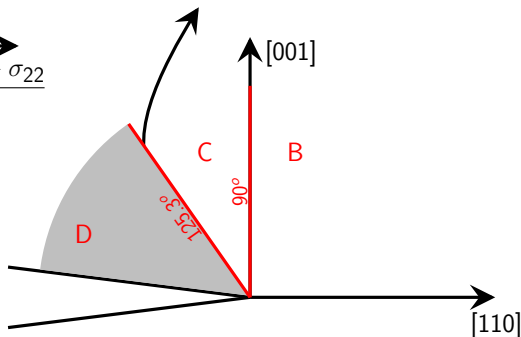


Construction of a solution of the crack problem

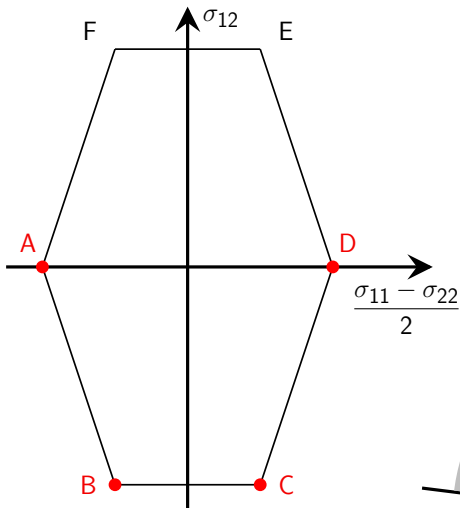


solution

- $\sigma_{12}^C = -\sqrt{3}\tau_{oc}$
- $\sigma_{22}^C = -\sqrt{6}\tau_{oc}$
- $\sigma_{11}^C = 3/2\sqrt{6}\tau_{oc}$

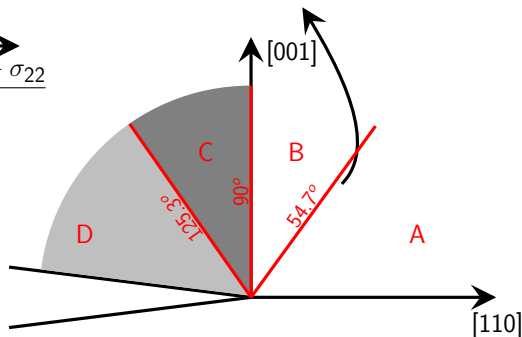


Construction of a solution of the crack problem

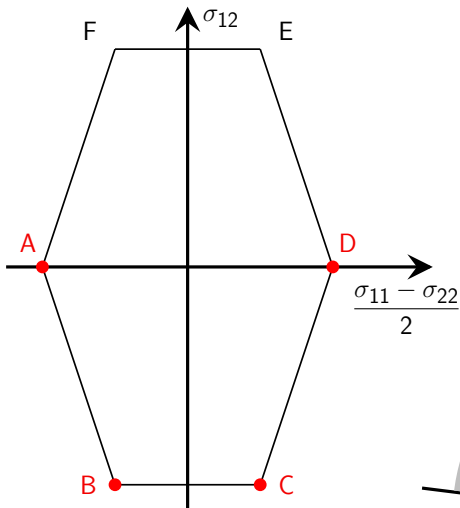


solution

- $\sigma_{12}^B = -\sqrt{3}\tau_{oc}$
- $\sigma_{22}^B = 2\sqrt{6}\tau_{oc}$
- $\sigma_{11}^B = 3/2\sqrt{6}\tau_{oc}$

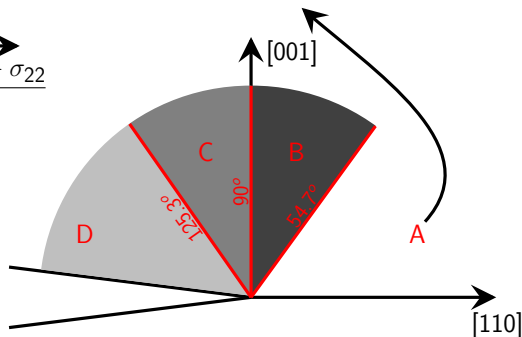


Construction of a solution of the crack problem

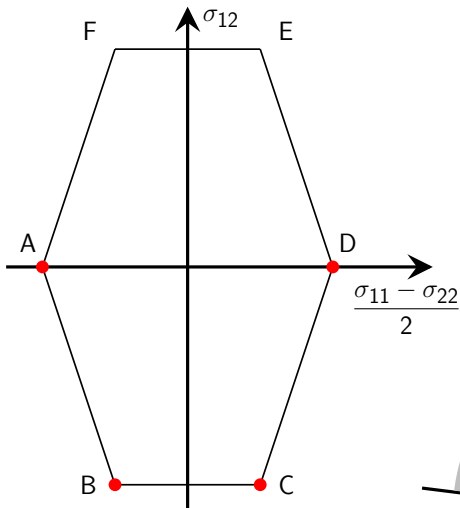


solution

- $\sigma_{12}^A = 0$
- $\sigma_{22}^A = 2\sqrt{6}\tau_{oc}$
- $\sigma_{11}^A = 2\sqrt{6}\tau_{oc}$

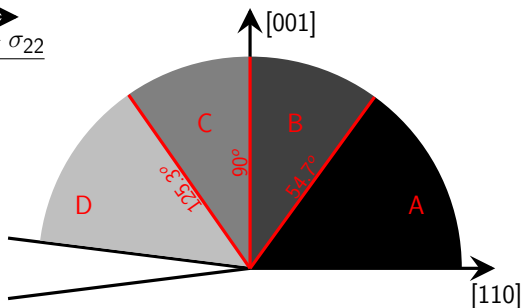


Construction of a solution of the crack problem



solution

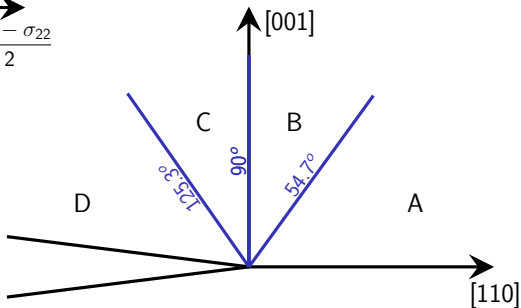
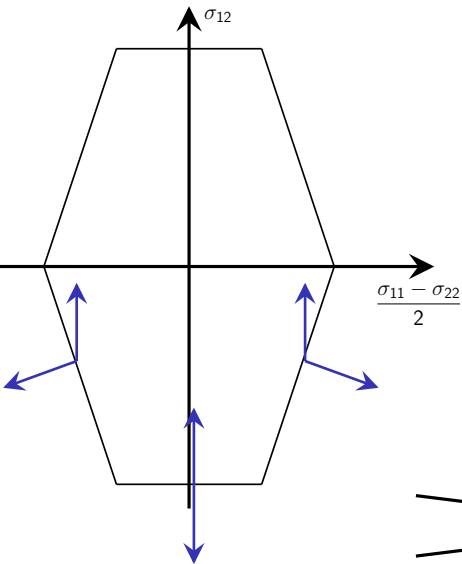
- $\sigma_{12}^A = 0$
- $\sigma_{22}^A = 2\sqrt{6}\tau_{oc}$ acceptable !!
- $\sigma_{11}^A = 2\sqrt{6}\tau_{oc}$



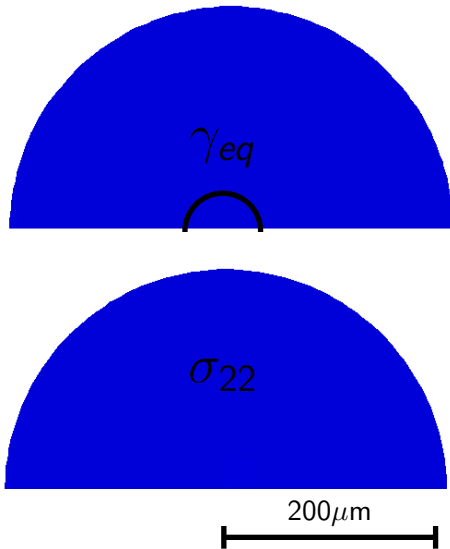
A systematic derivation method

Discontinuity condition:

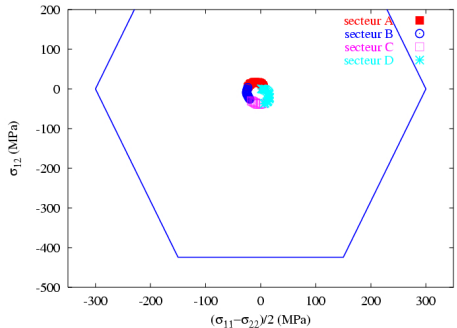
$$\tan 2\theta = 2 \frac{N_1^{(s)} N_2^{(s)}}{N_2^{(s)2} - N_1^{(s)2}}$$



Finite Element analysis - Orientation $S \succ (001)[110]$



$$\dot{\gamma}_{eq} = \sum_{s=0}^{s=12} |\dot{\gamma}^s|$$

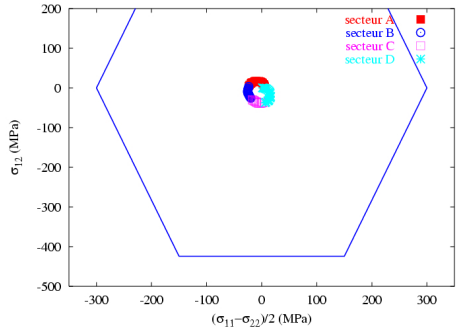
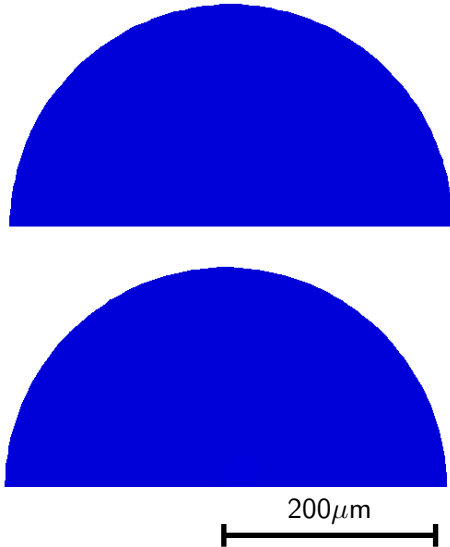


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

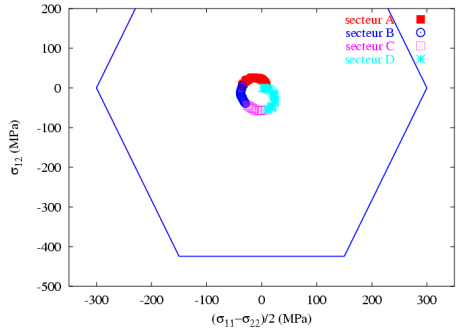
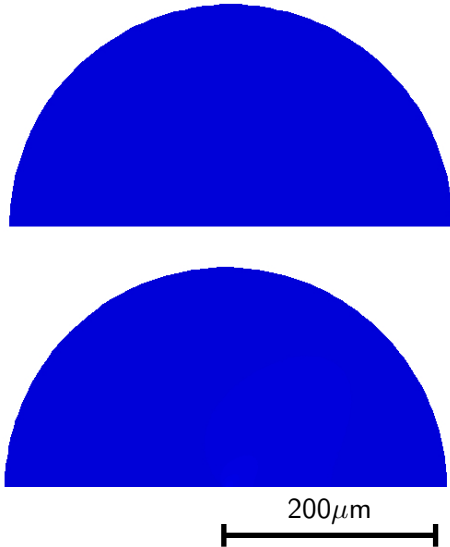


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

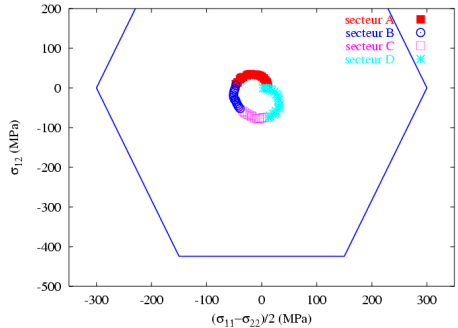
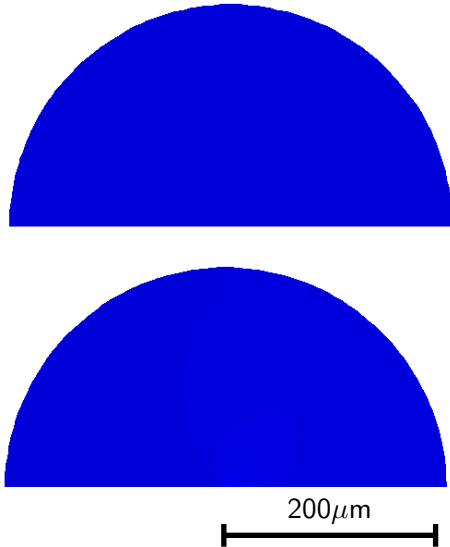


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

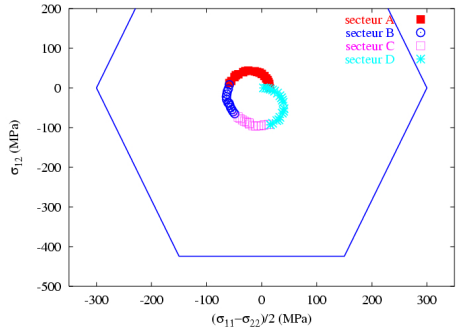
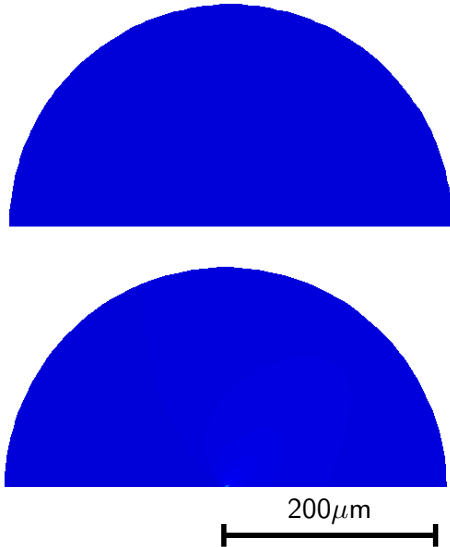


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

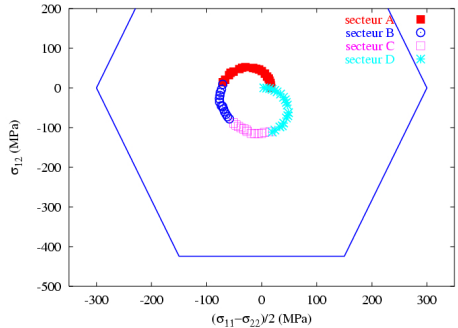
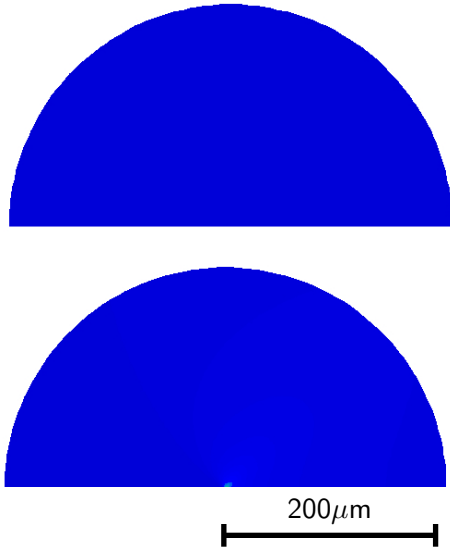


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

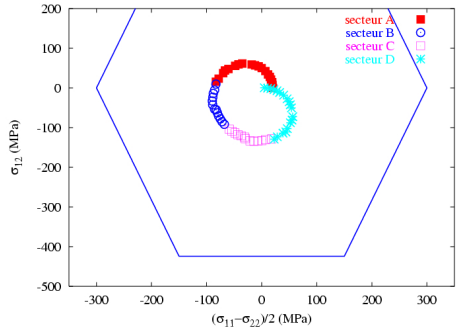
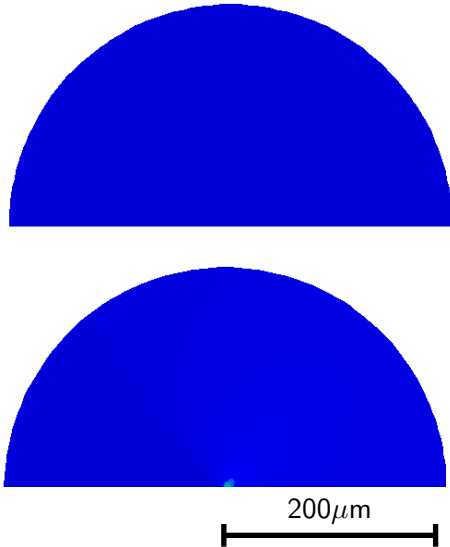


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

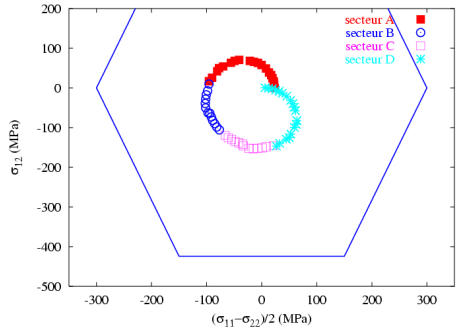
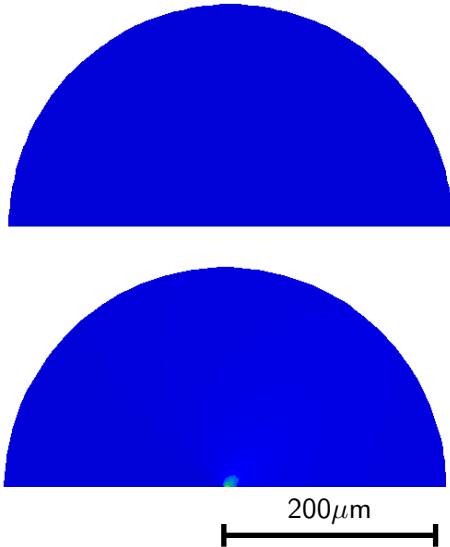


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

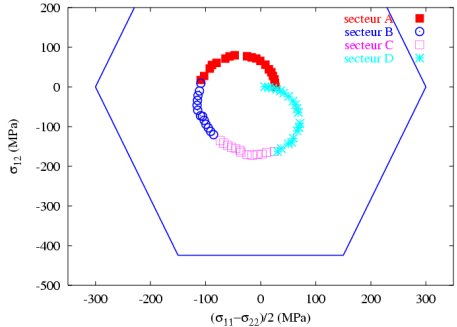
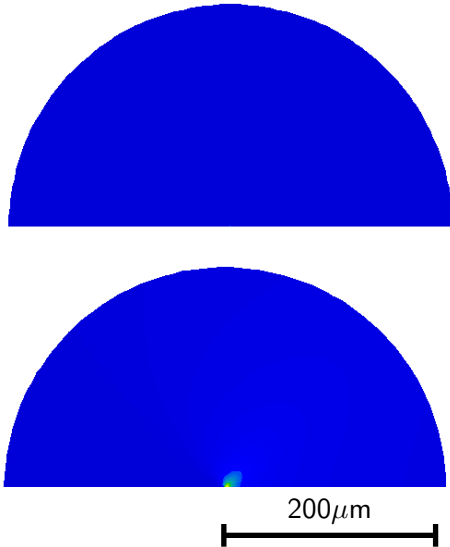


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

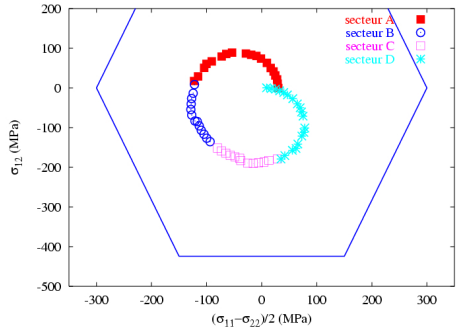
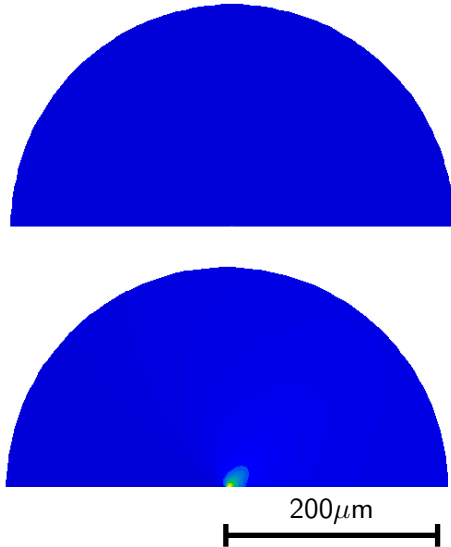


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

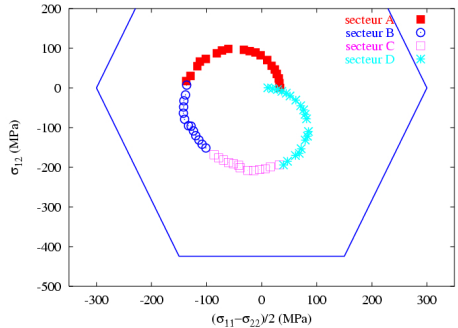
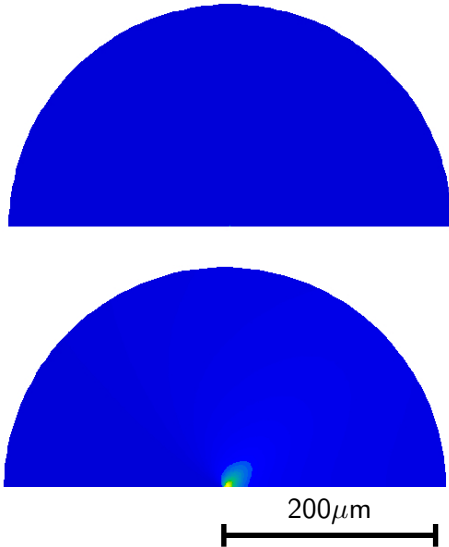


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

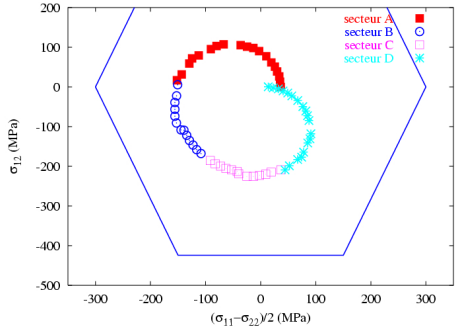
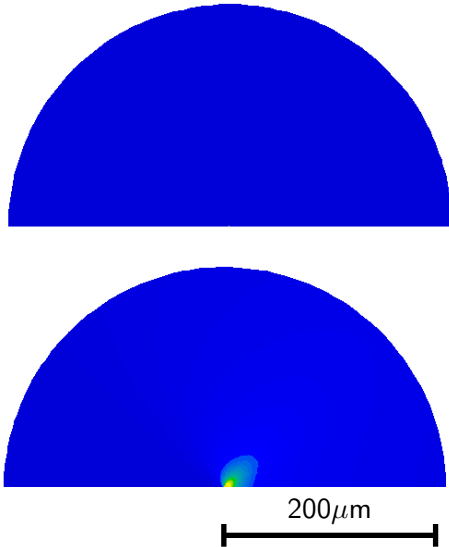


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

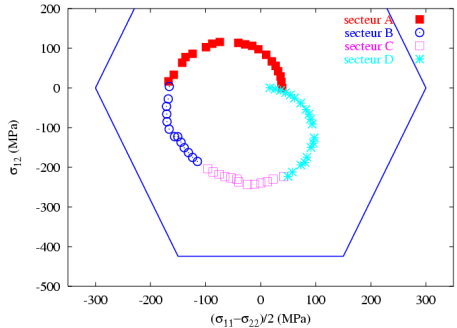
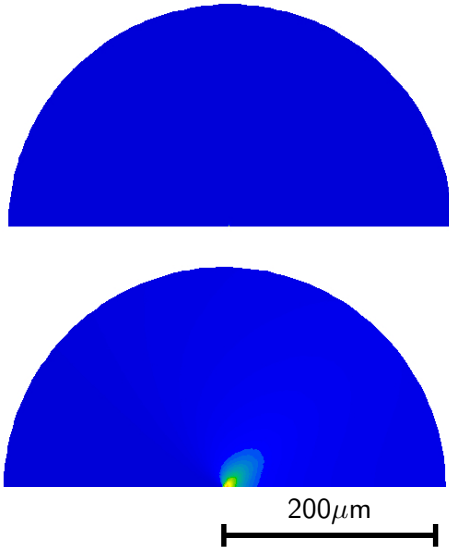


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

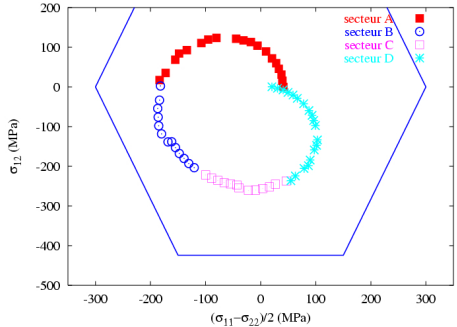
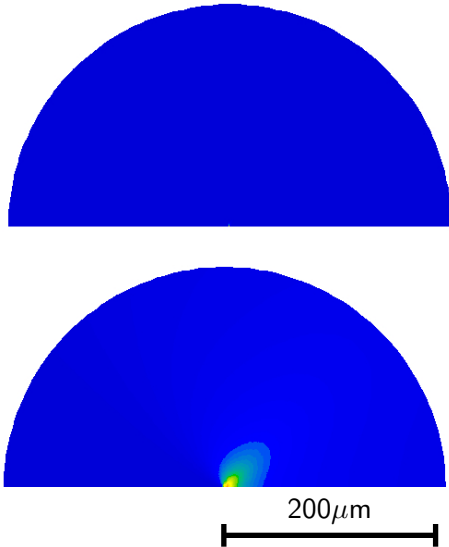


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

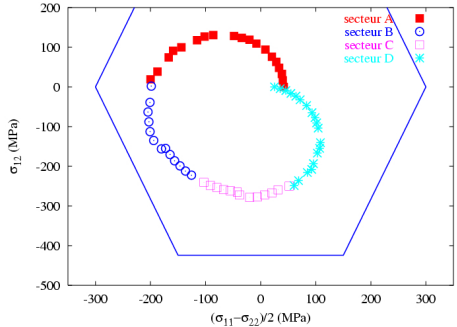
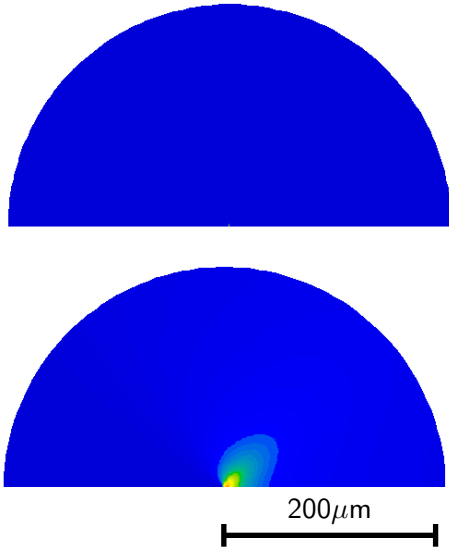


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

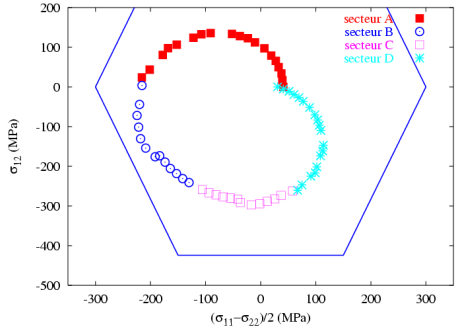
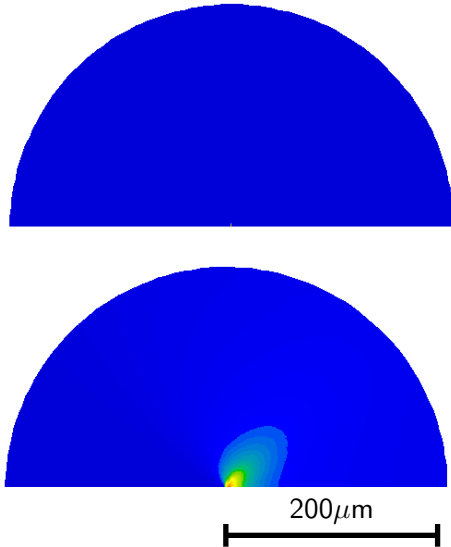


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

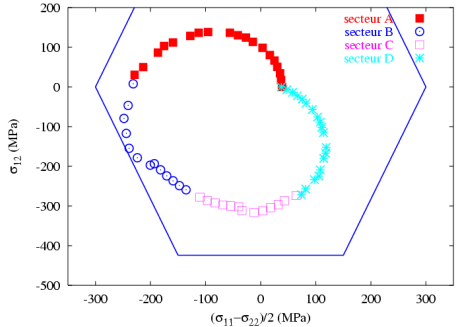
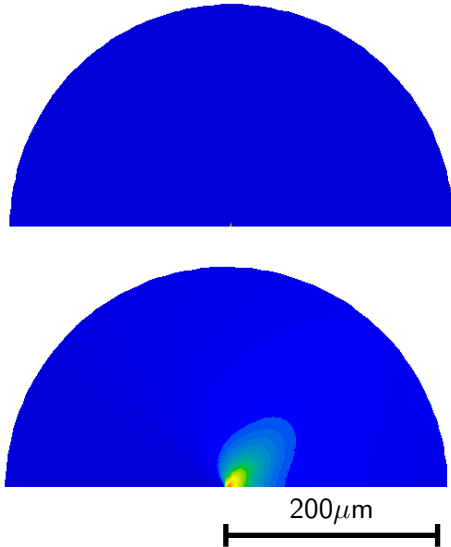


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

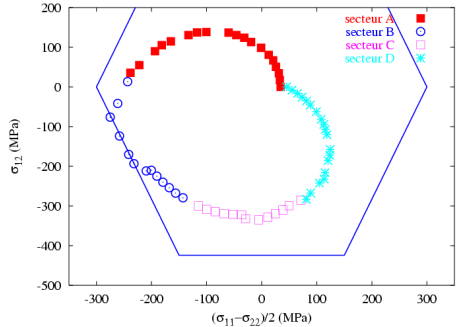
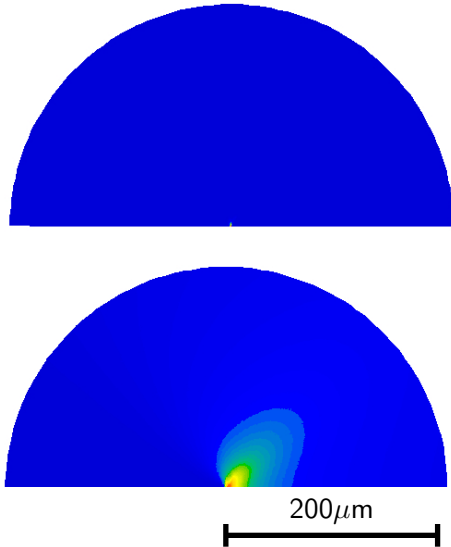


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

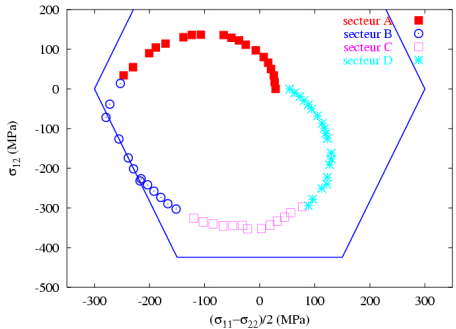
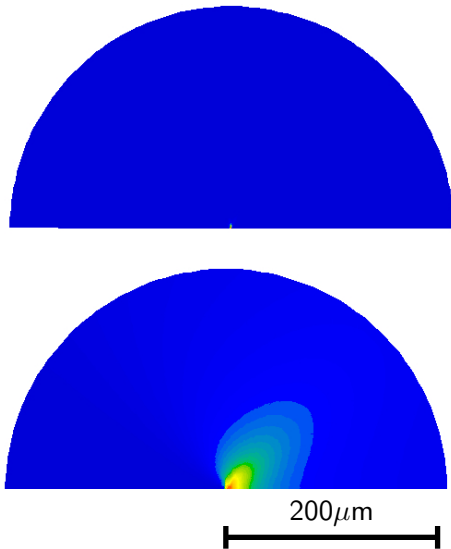


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

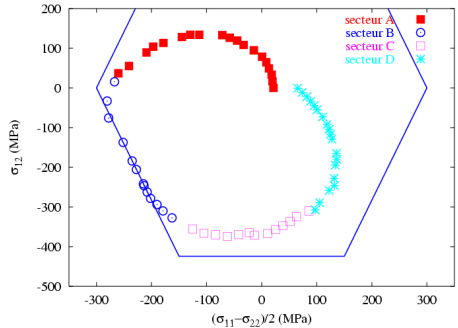
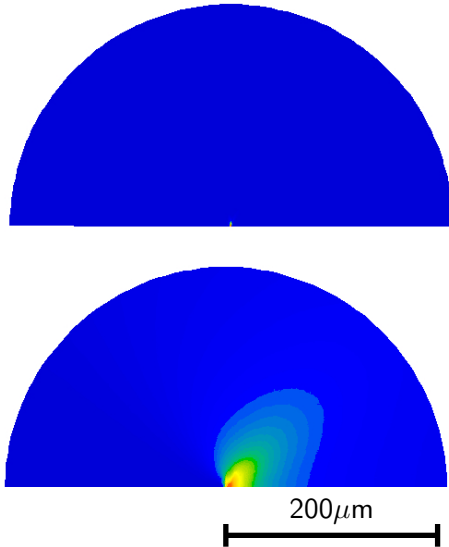


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

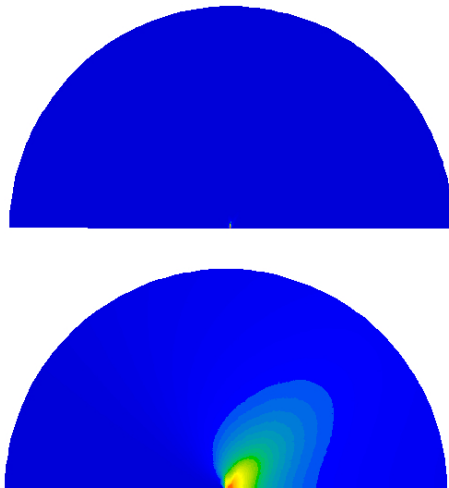


◀ Start

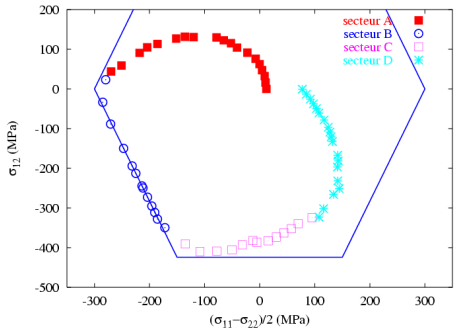
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

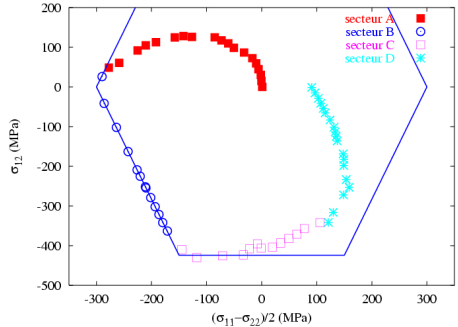
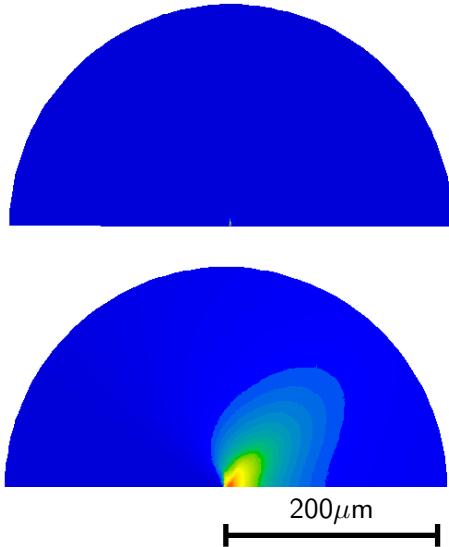


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

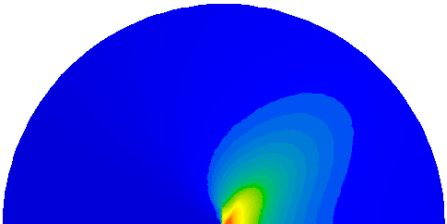
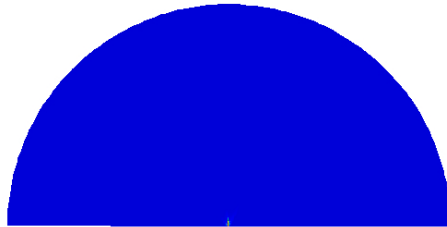


◀ Start

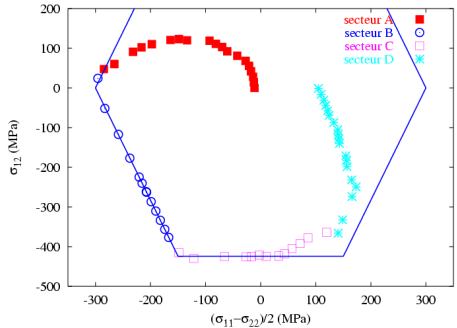
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μ m

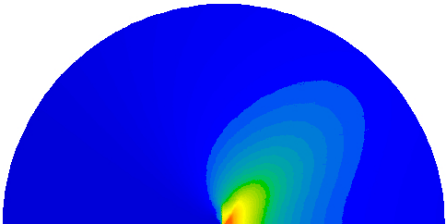
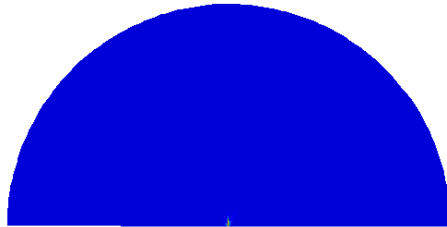


◀ Start

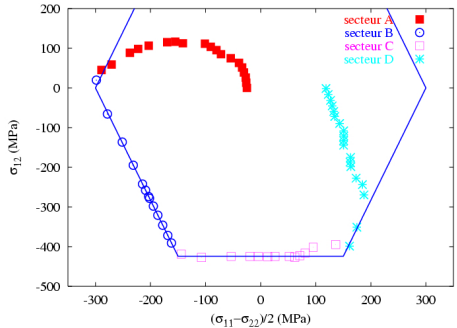
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

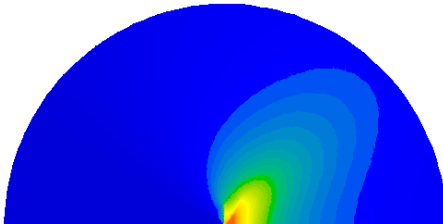
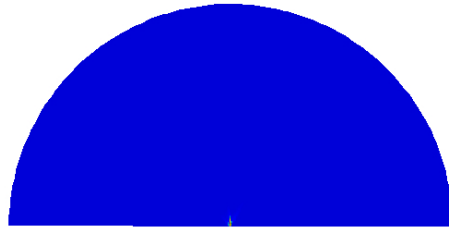


◀ Start

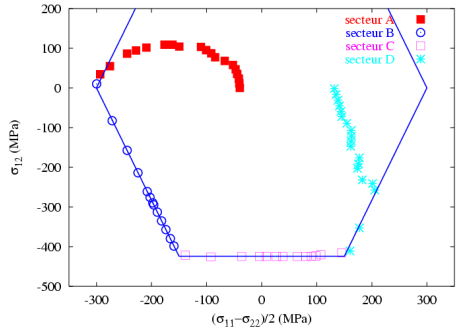
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

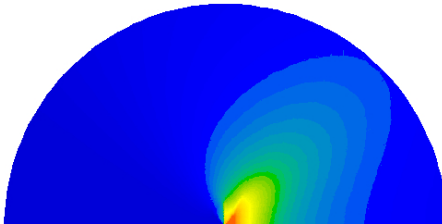
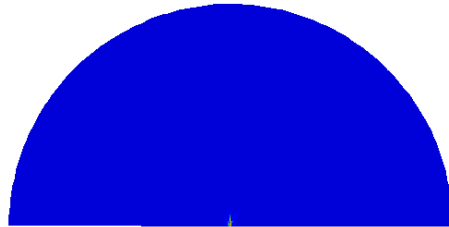


◀ Start

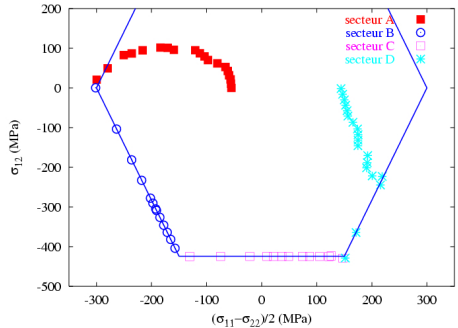
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

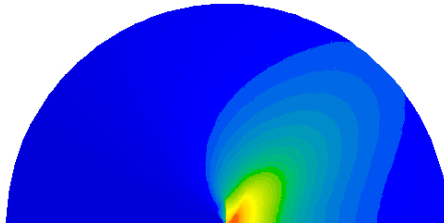
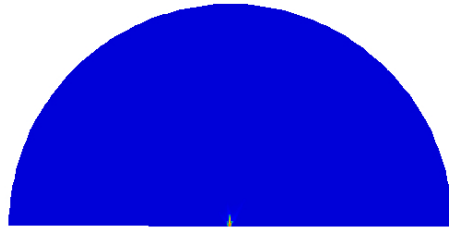


◀ Start

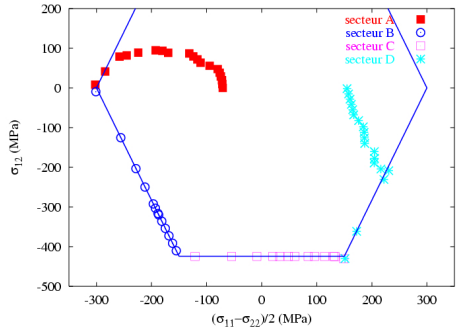
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μ m

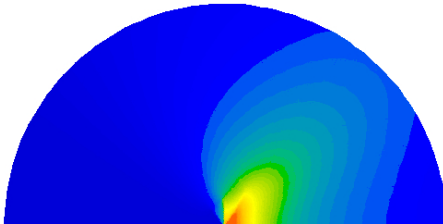


◀ Start

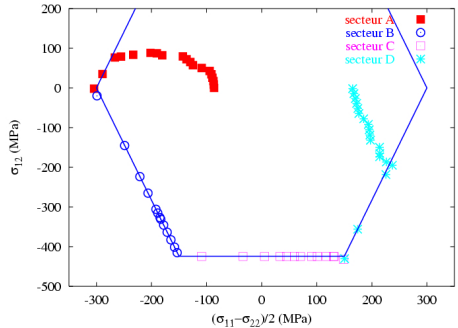
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

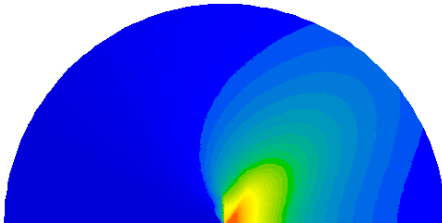
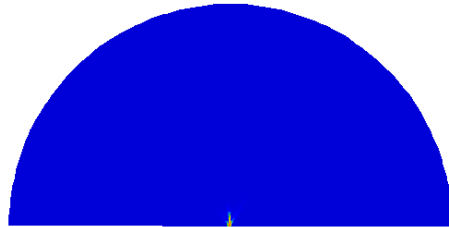


◀ Start

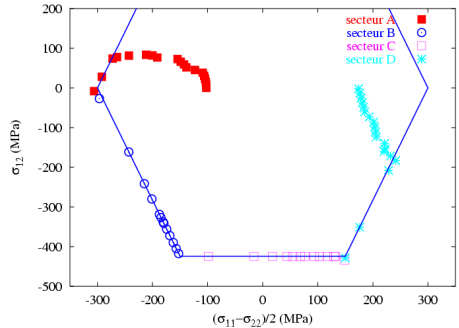
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

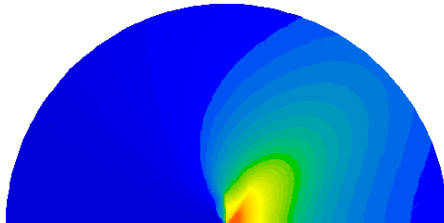
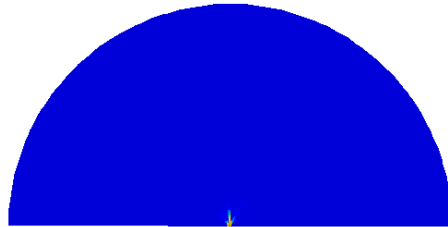


◀ Start

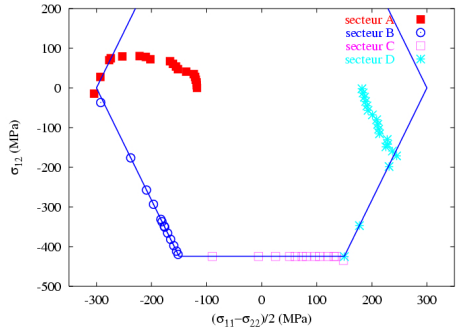
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

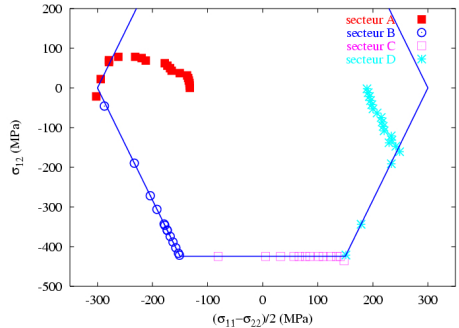
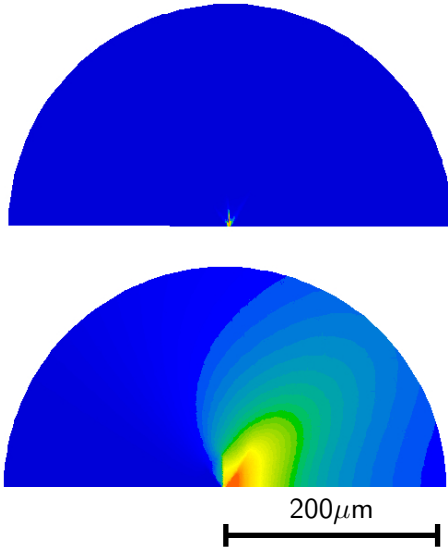


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

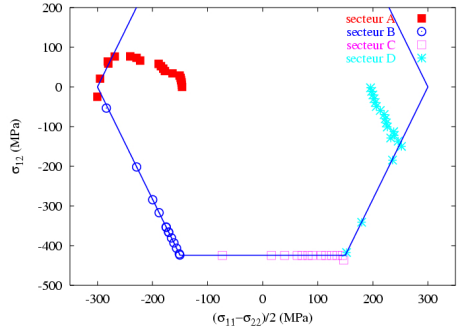
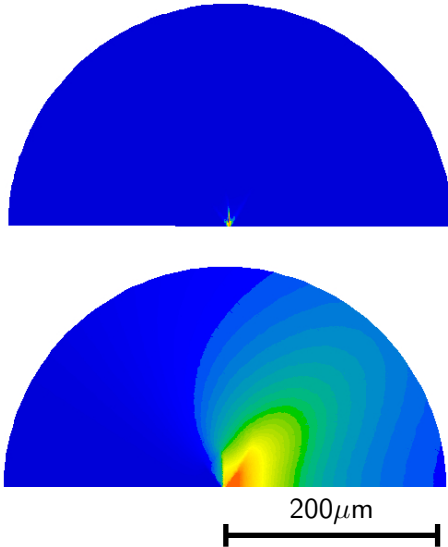


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

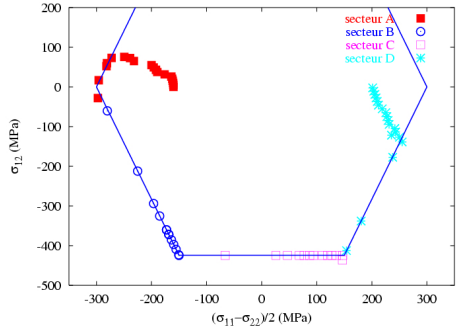
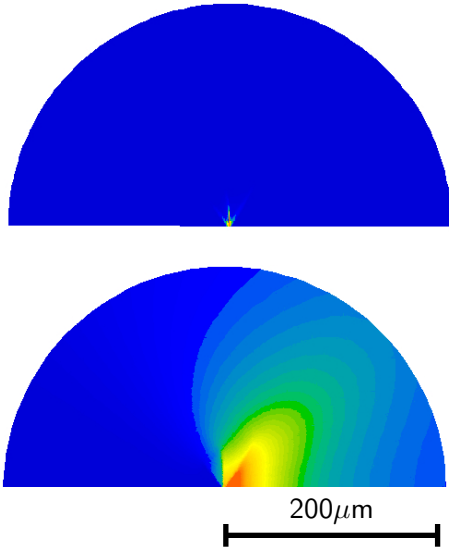


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

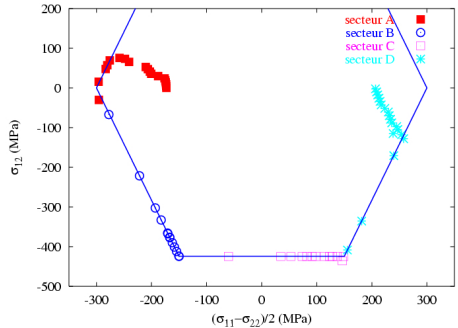
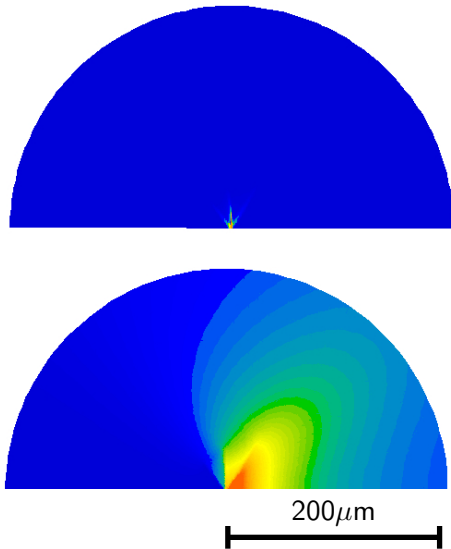


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

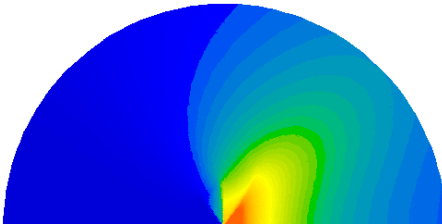
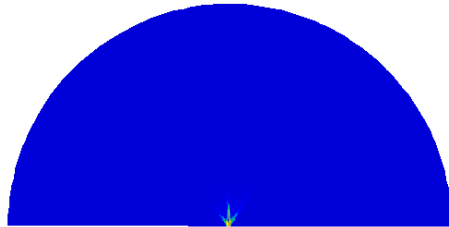


◀ Start

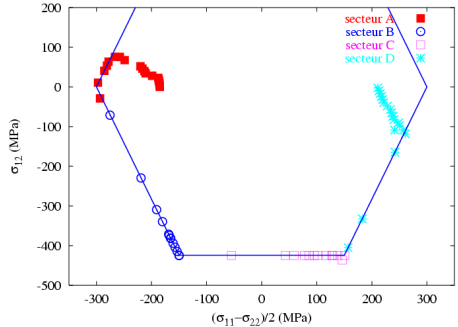
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



$200\mu\text{m}$

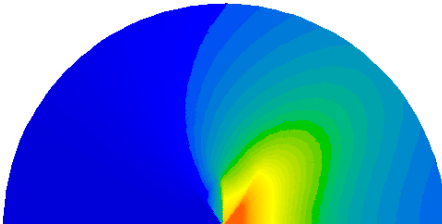
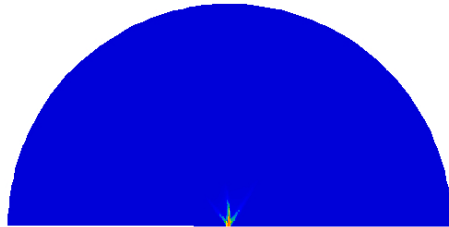


◀ Start

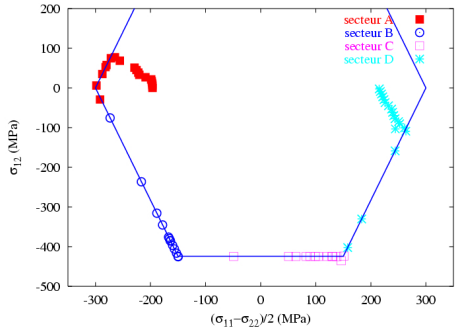
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

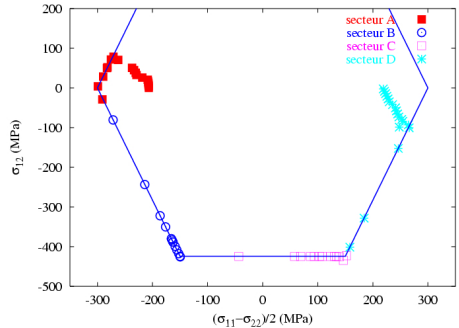
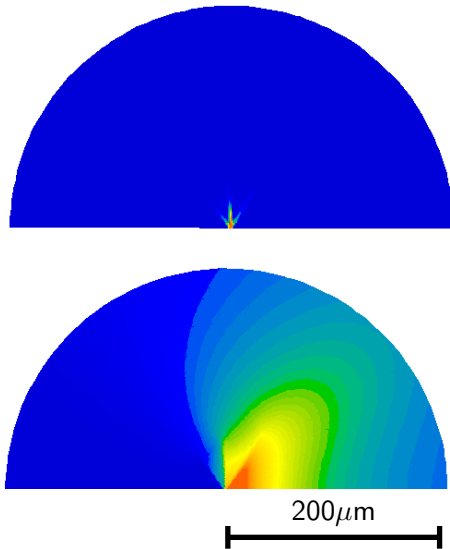


◀ Start

▶ Animation

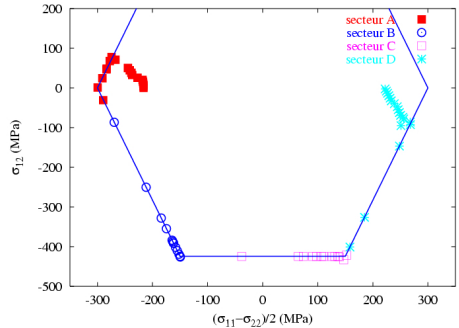
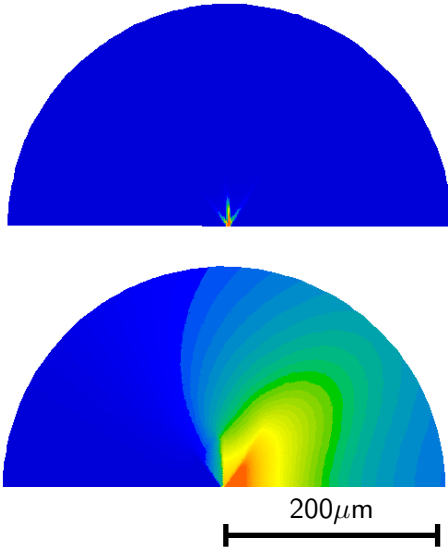
▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



◀ Start ▶ Animation ▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

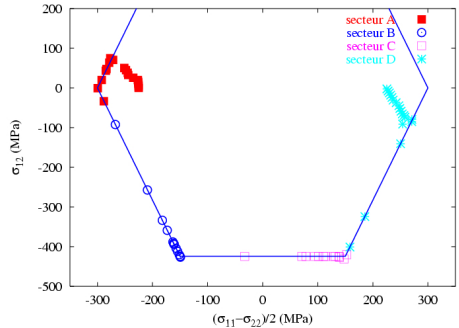
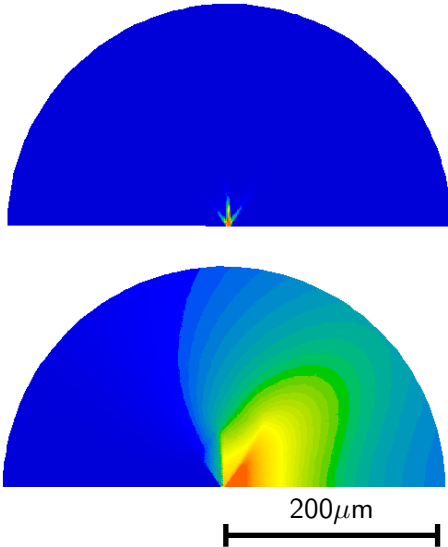


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

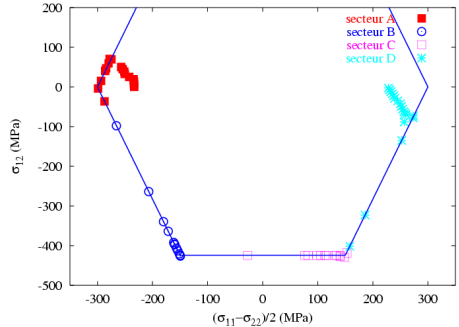
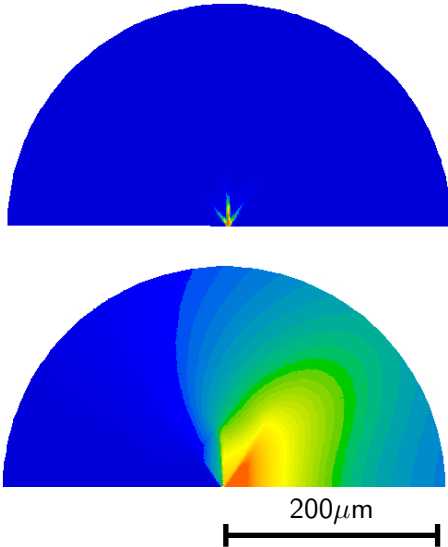


◀ Start

▶ Animation

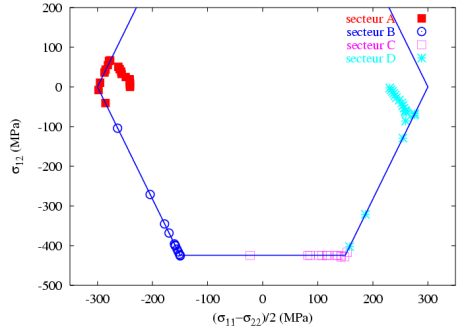
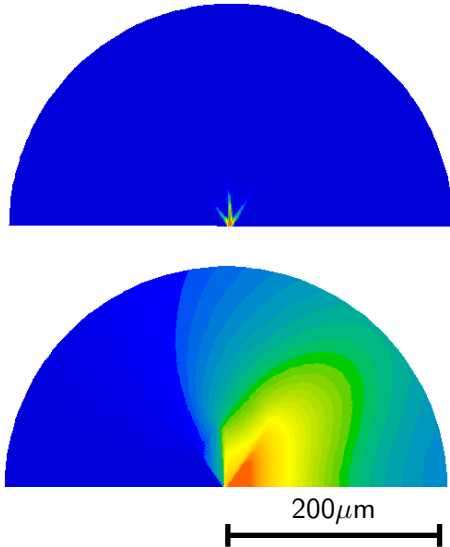
▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



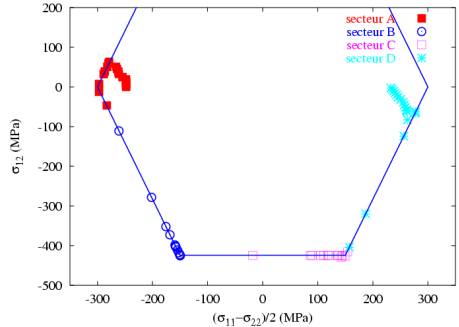
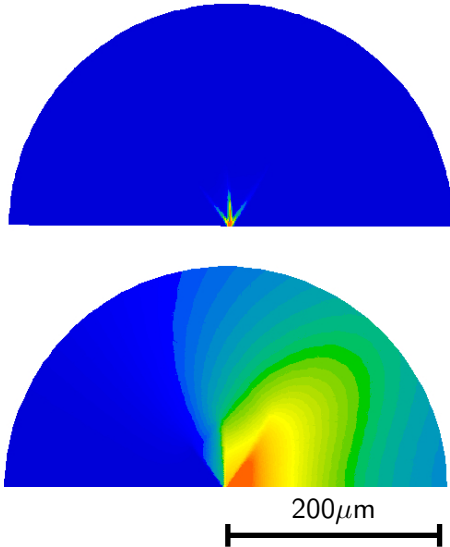
◀ Start ▶ Animation ▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



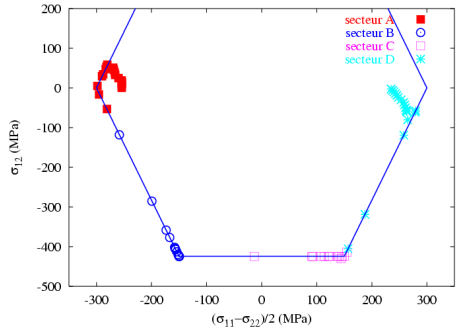
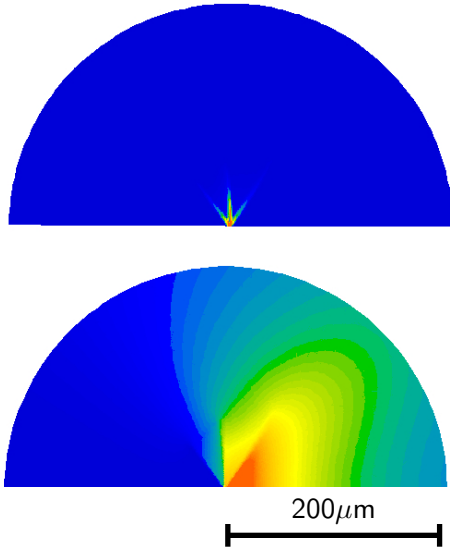
◀ Start ▶ Animation ▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



◀ Start ▶ Animation ▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

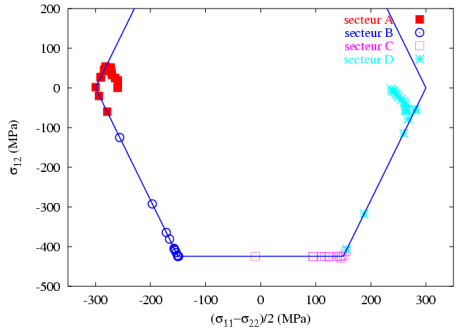
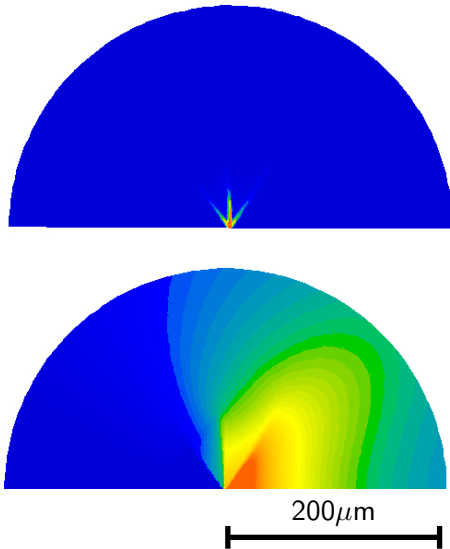


◀ Start

▶ Animation

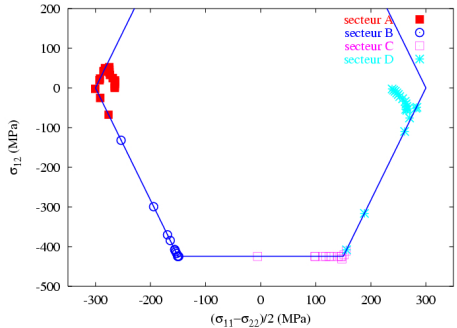
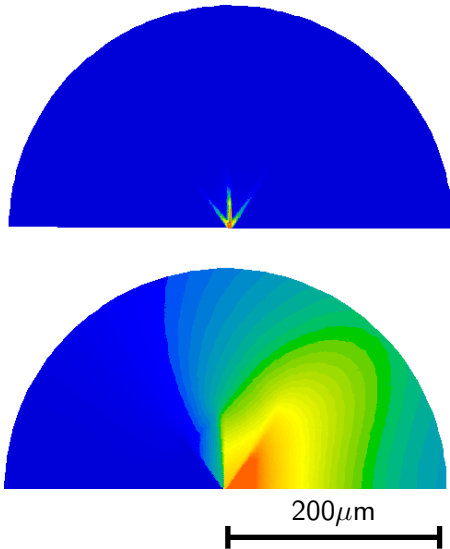
▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



◀ Start ▶ Animation ▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

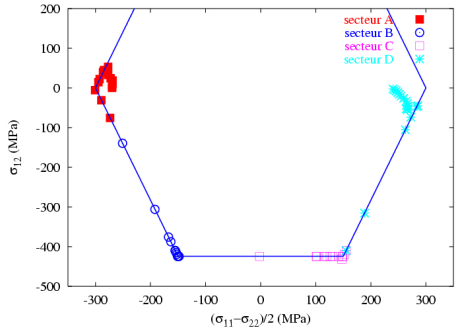
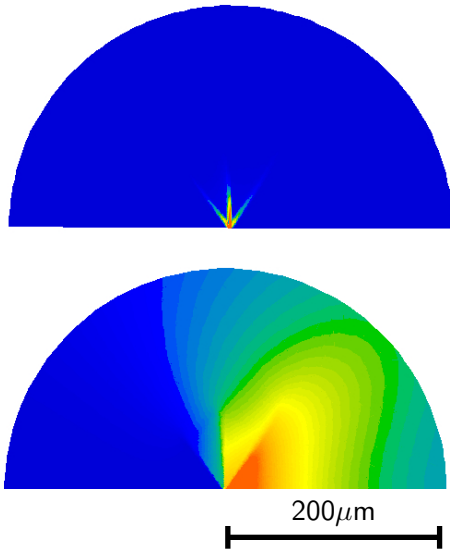


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

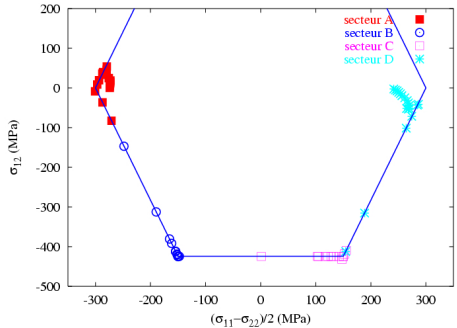
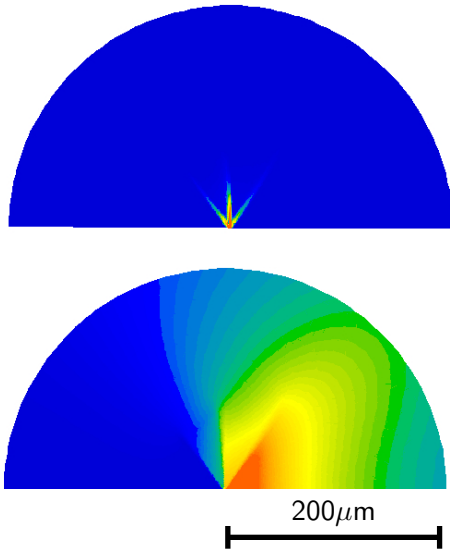


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

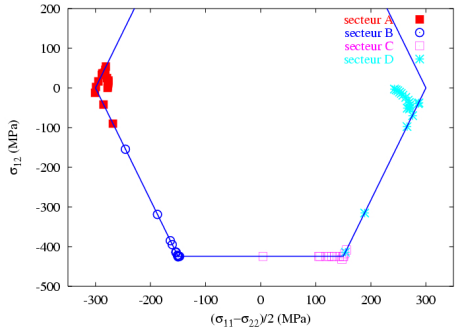
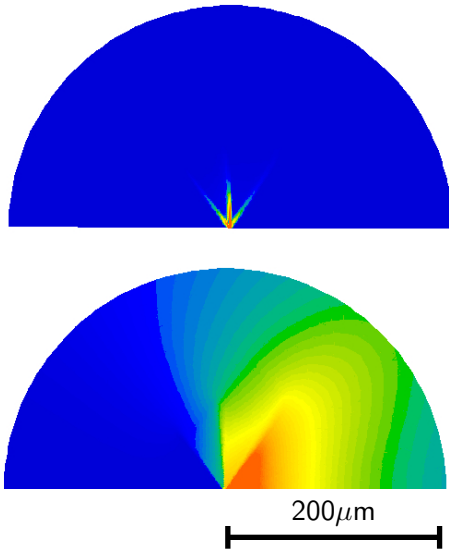


◀ Start

▶ Animation

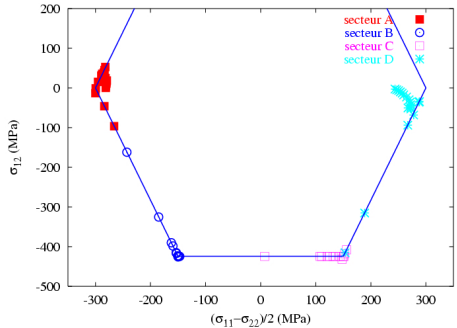
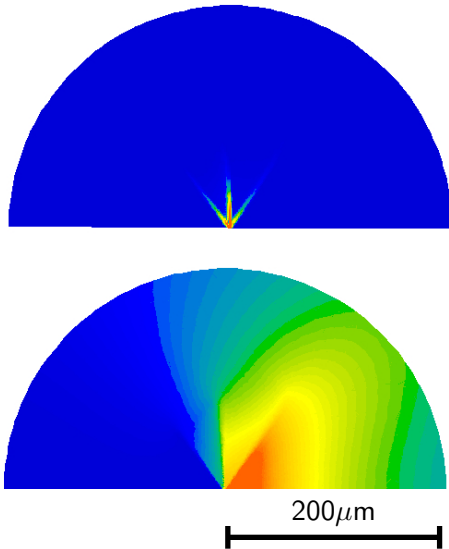
▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



◀ Start ▶ Animation ▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

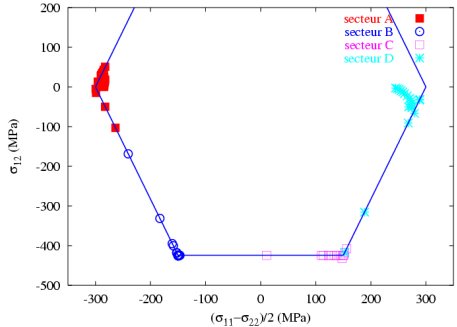
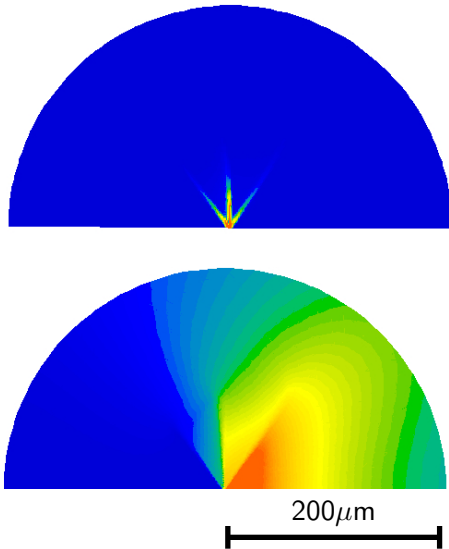


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

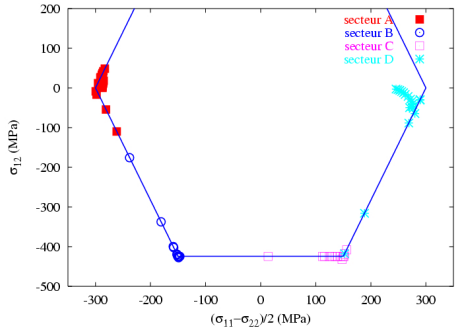
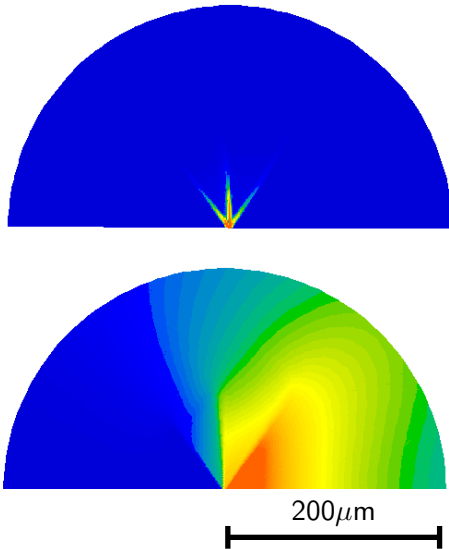


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

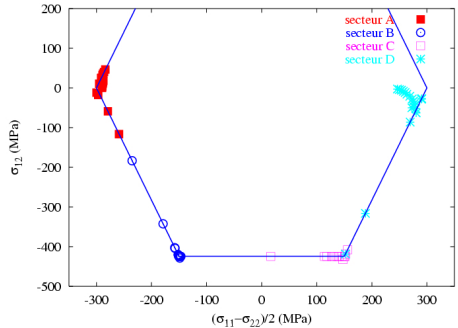
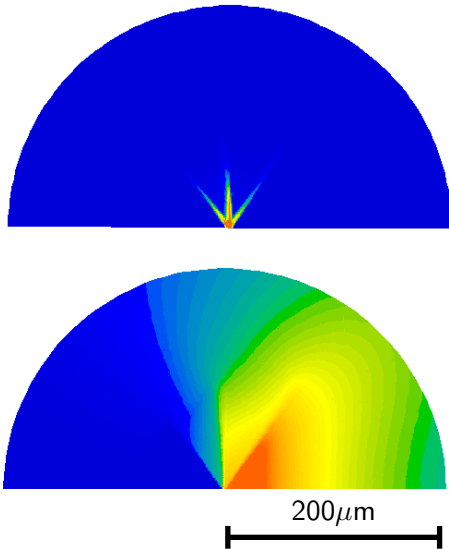


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

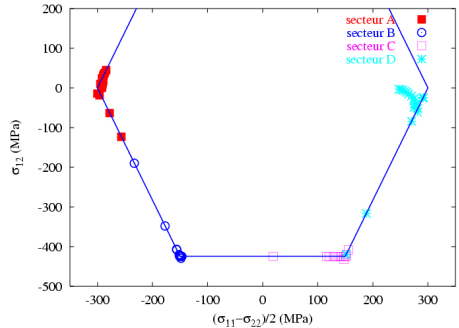
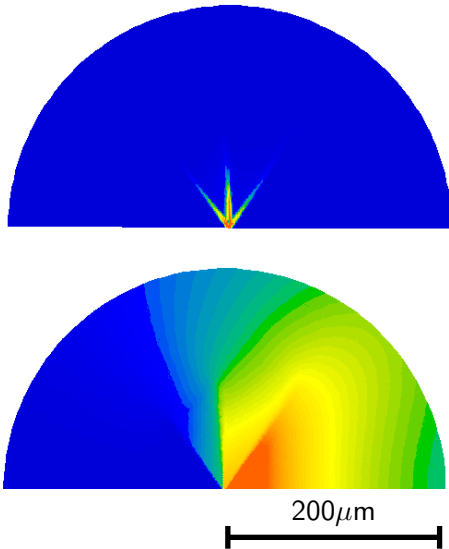


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

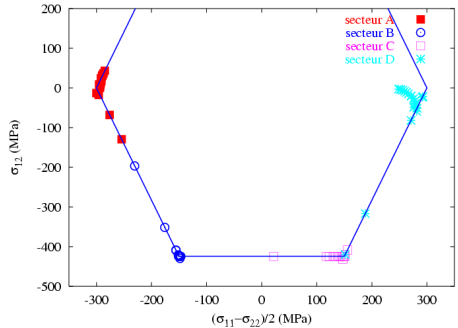
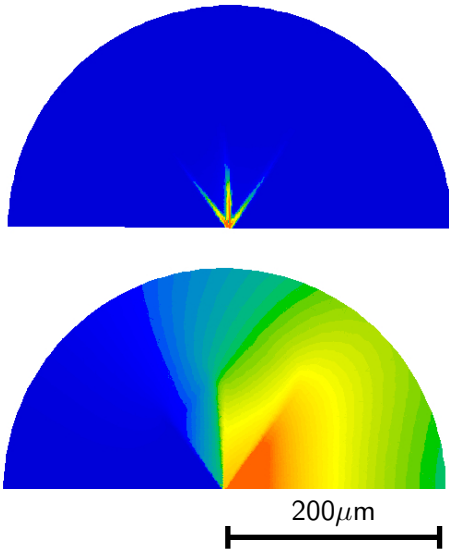


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

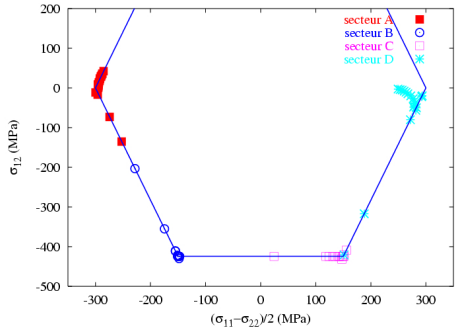
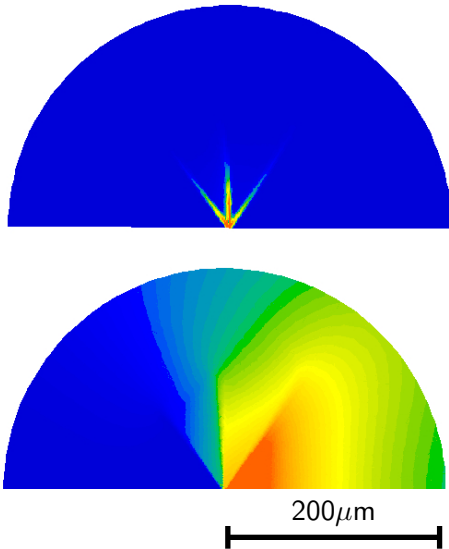


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

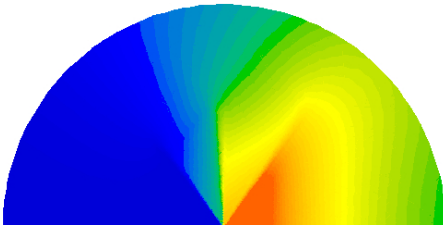
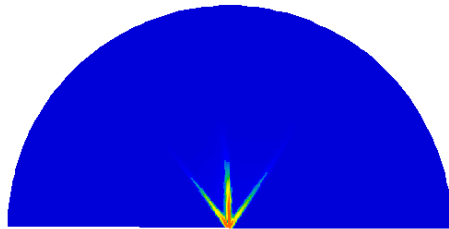


◀ Start

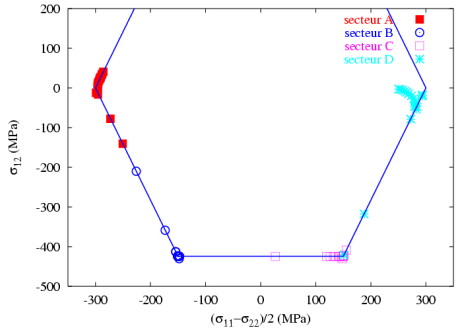
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

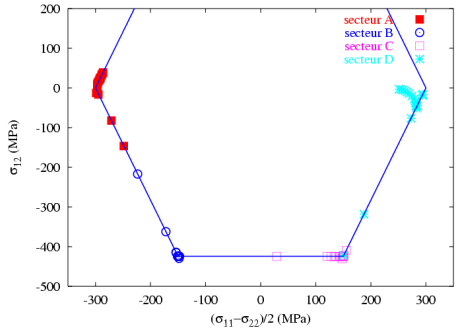
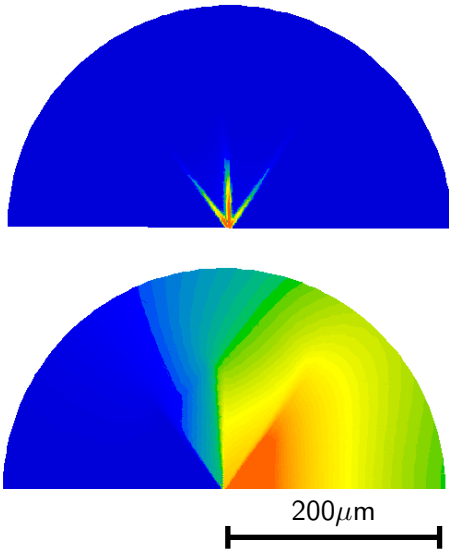


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

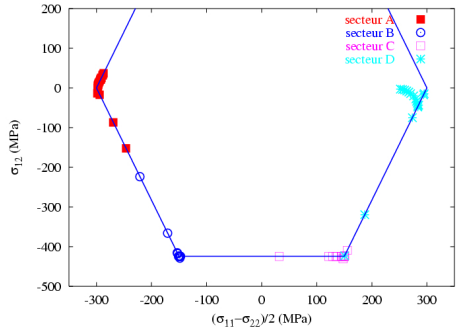
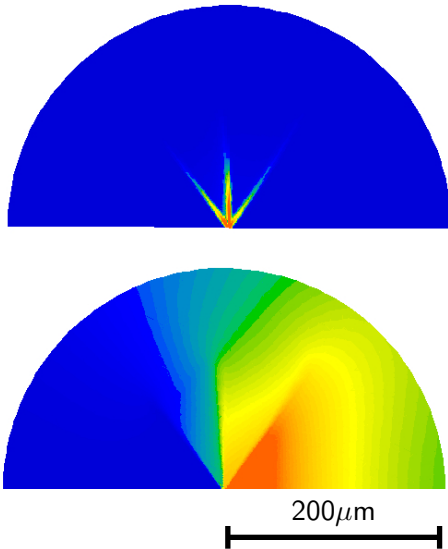


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

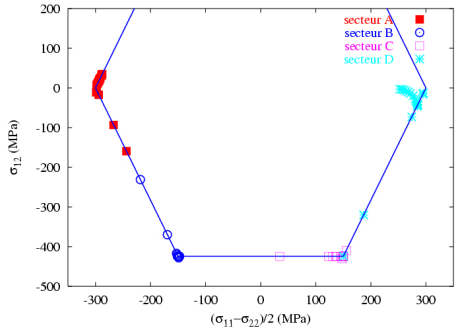
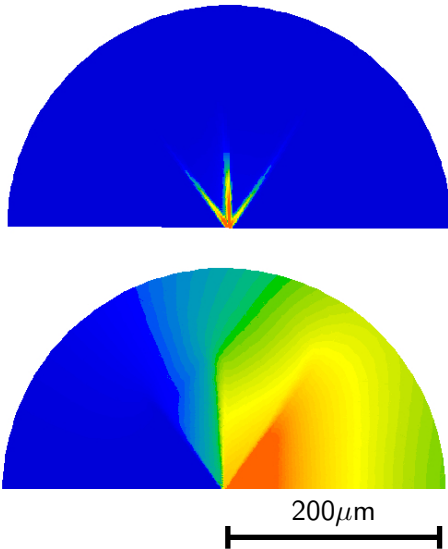


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

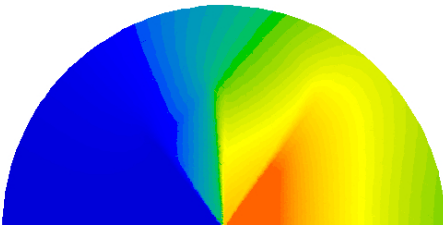
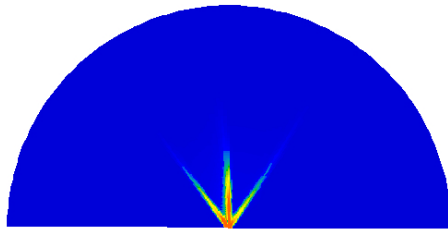


◀ Start

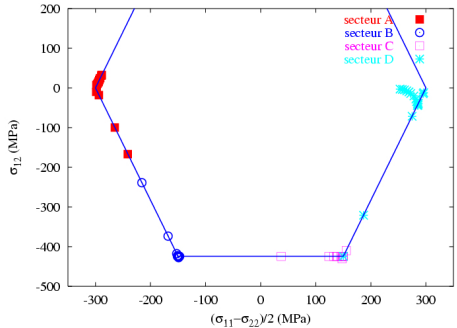
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

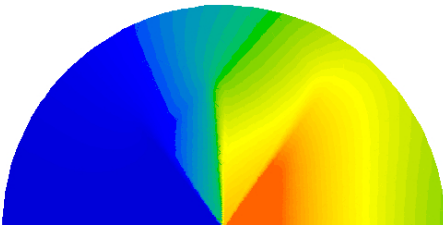
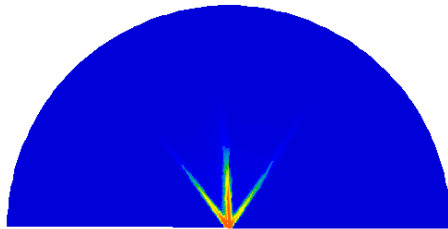


Start

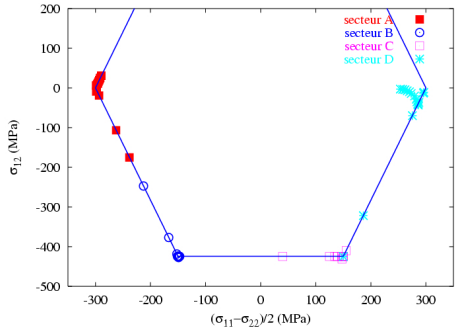
Animation

End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

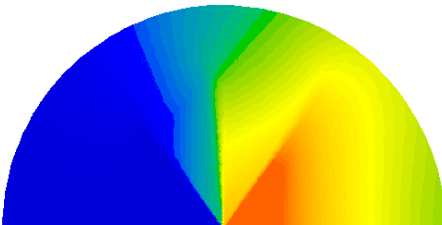
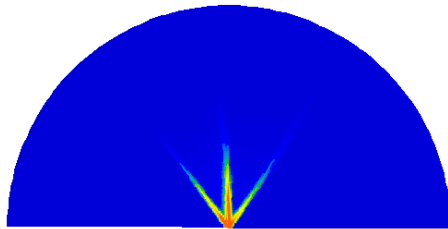


◀ Start

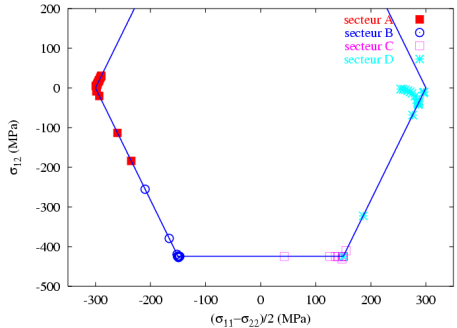
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

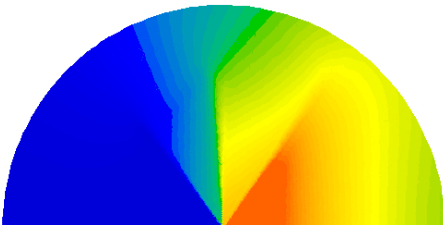
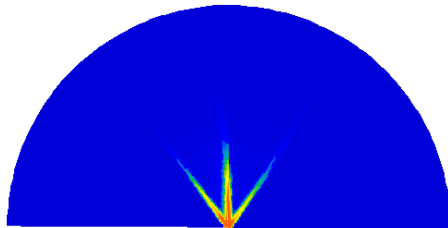


◀ Start

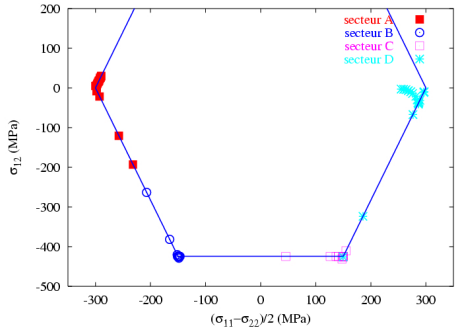
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

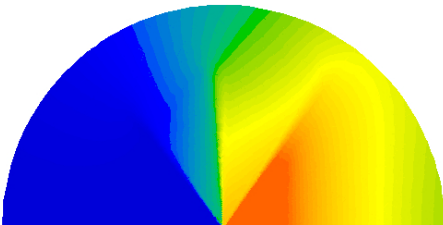
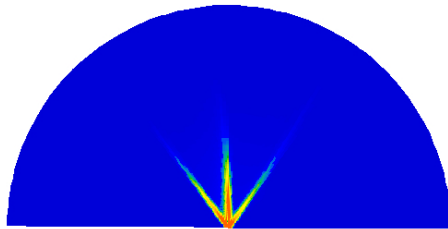


◀ Start

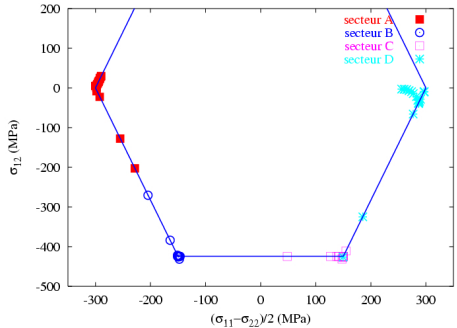
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

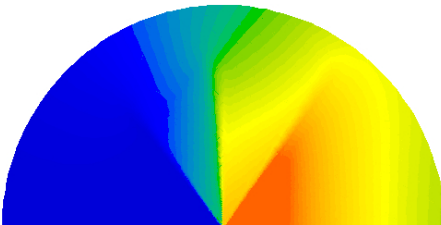
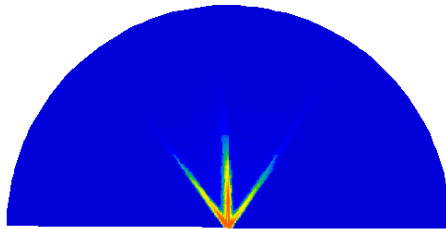


◀ Start

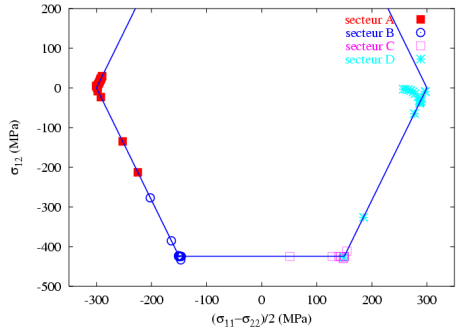
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

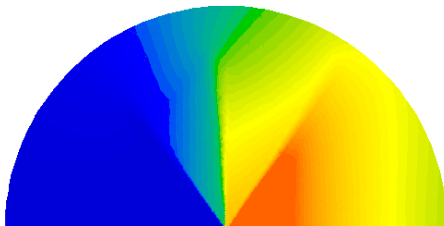
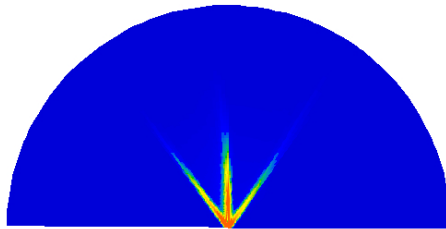


◀ Start

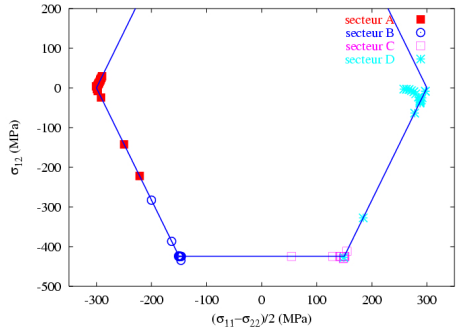
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

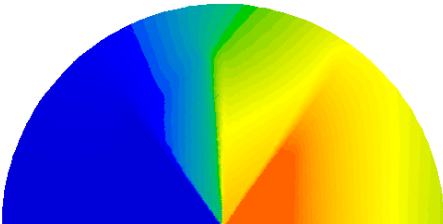
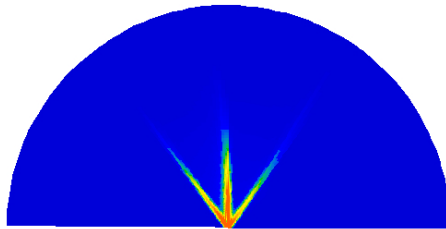


Start

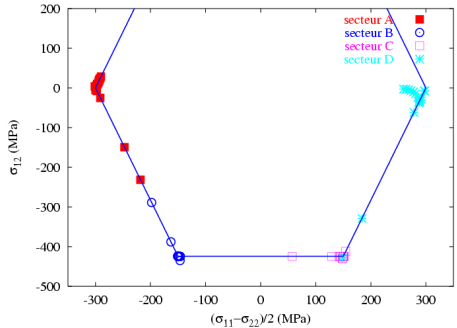
Animation

End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μ m

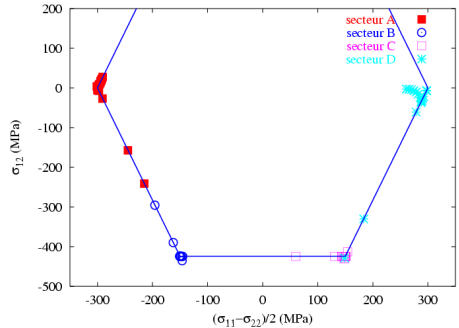
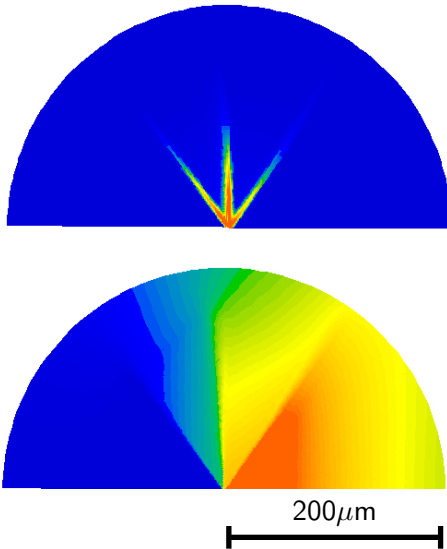


Start

Animation

End

Finite Element analysis - Orientation $S \succ (001)[110]$

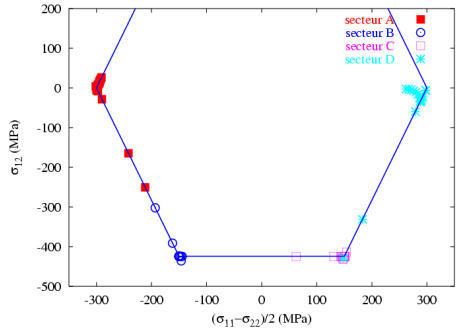
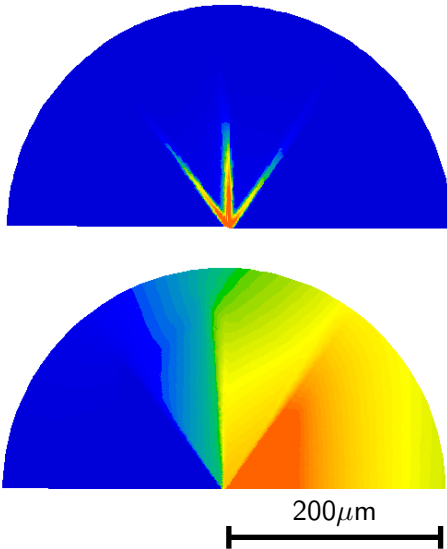


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

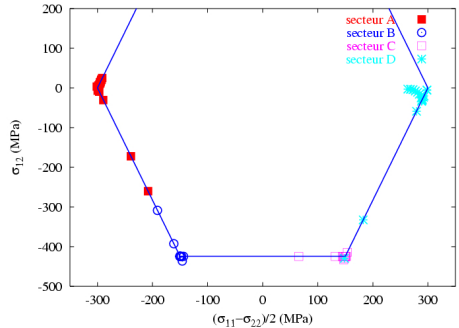
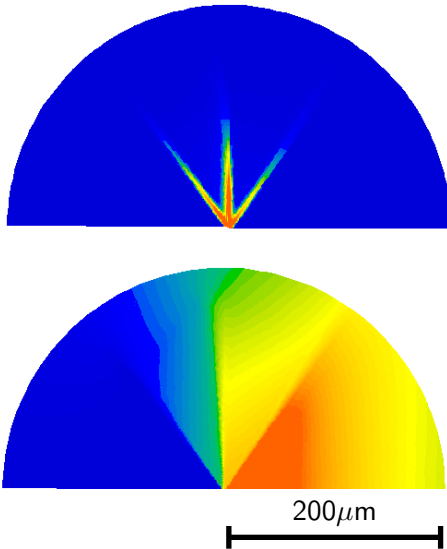


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

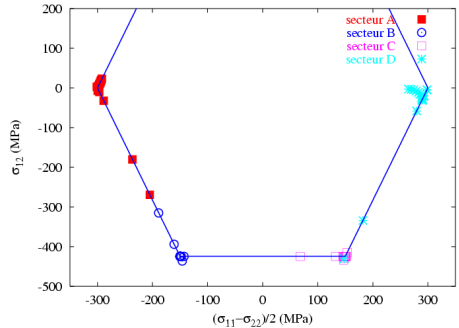
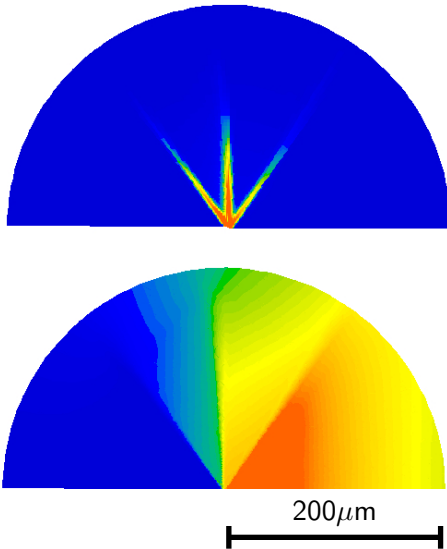


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

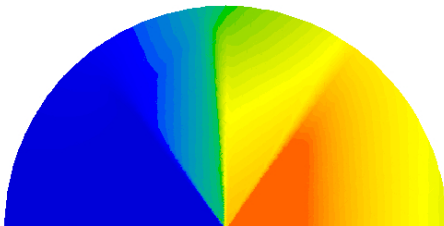
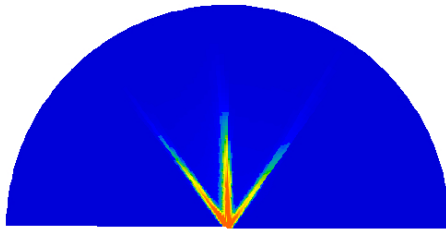


◀ Start

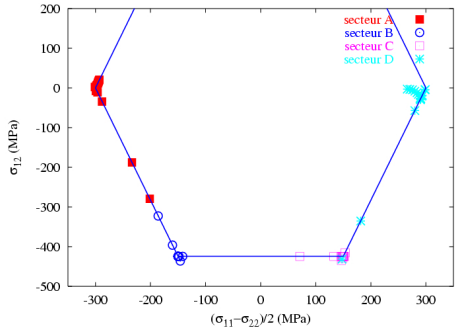
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

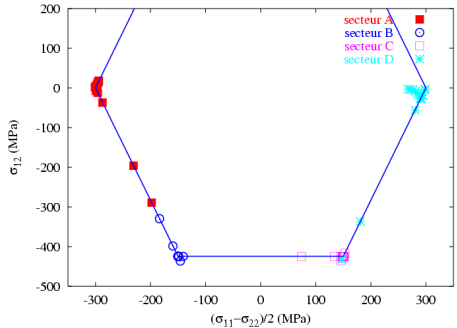
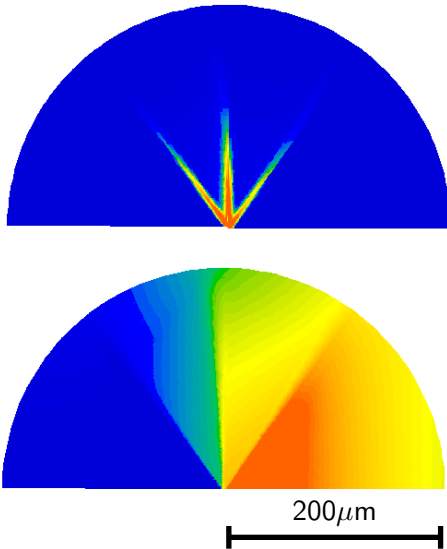


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

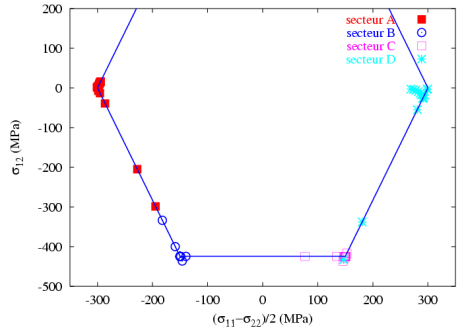
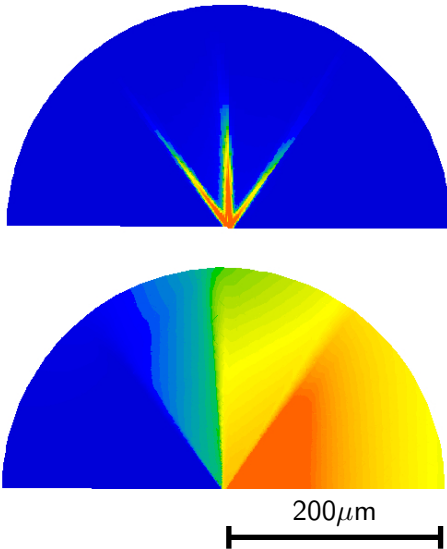


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

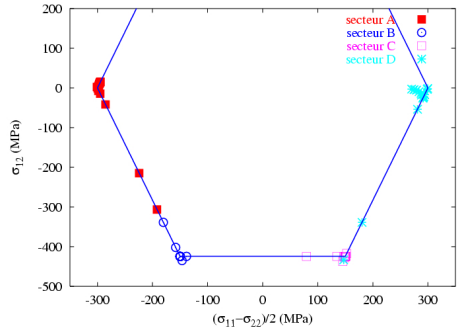
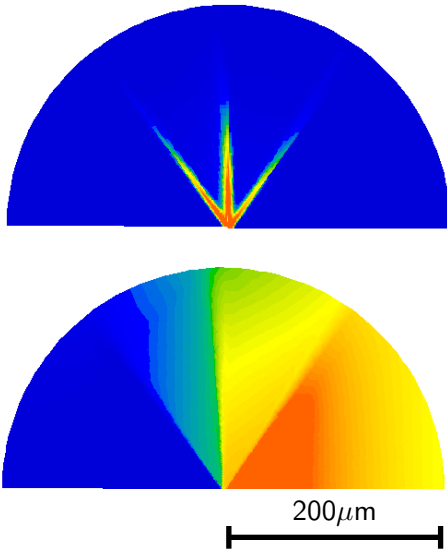


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

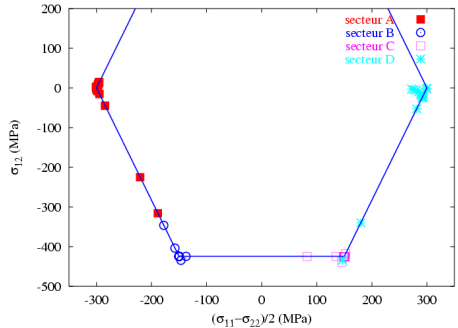
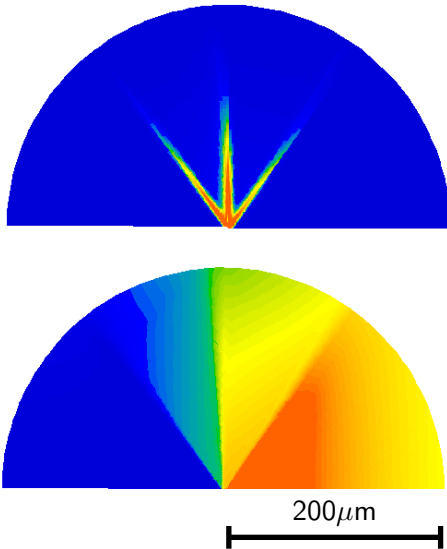


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

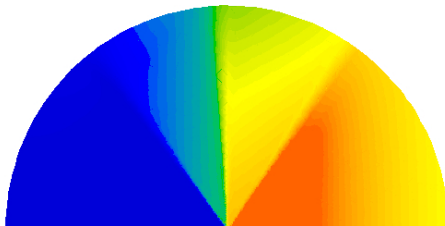
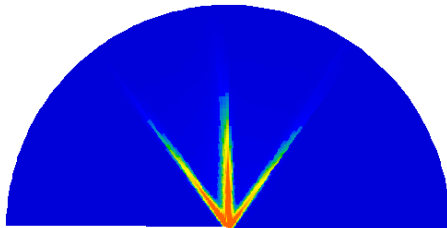


◀ Start

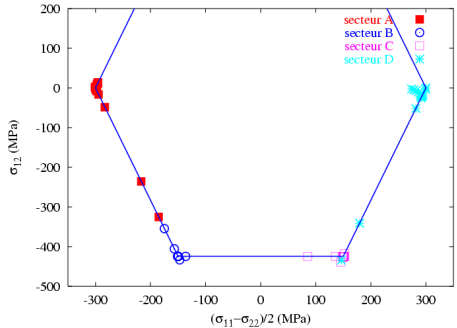
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

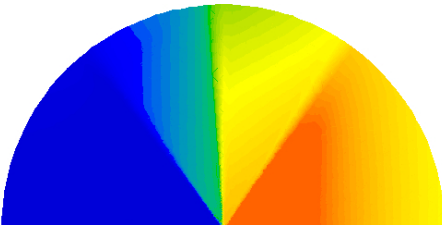
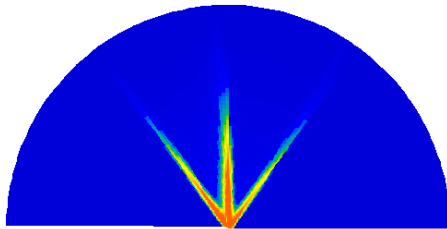


◀ Start

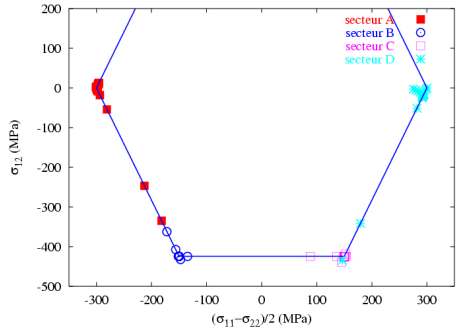
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

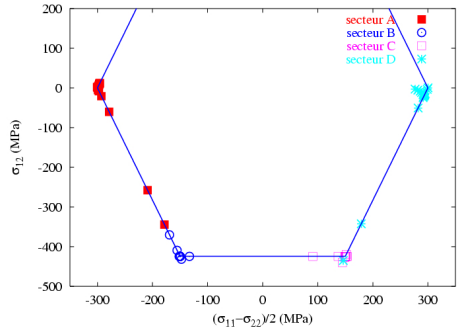
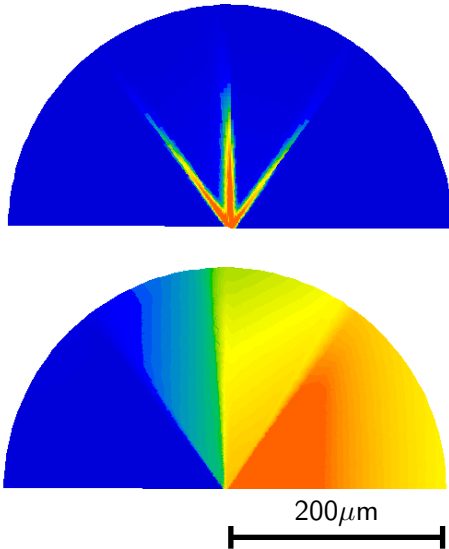


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

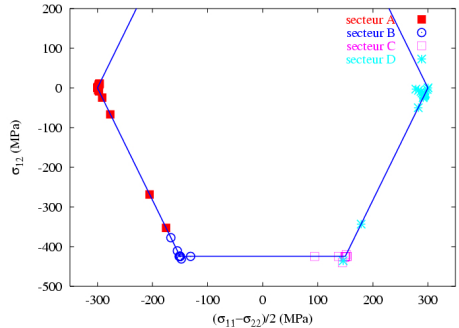
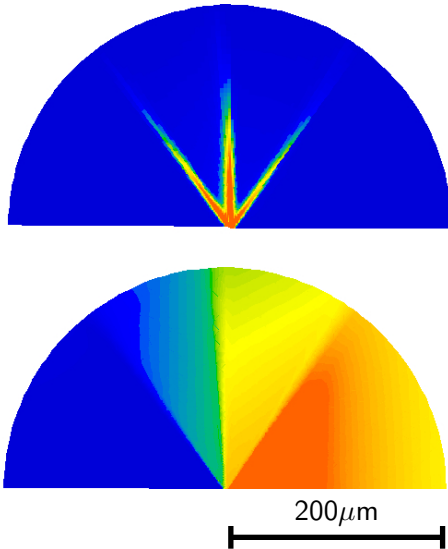


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

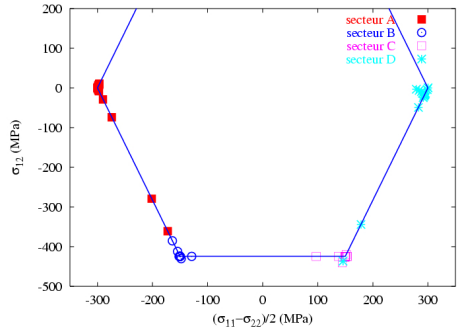
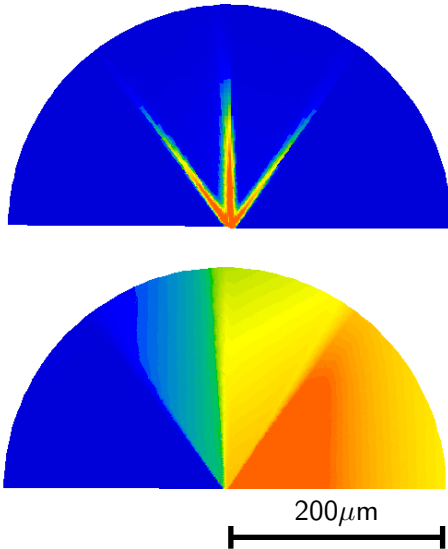


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

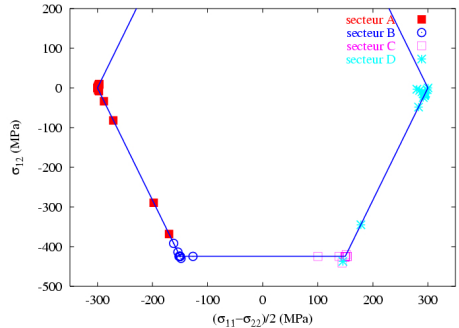
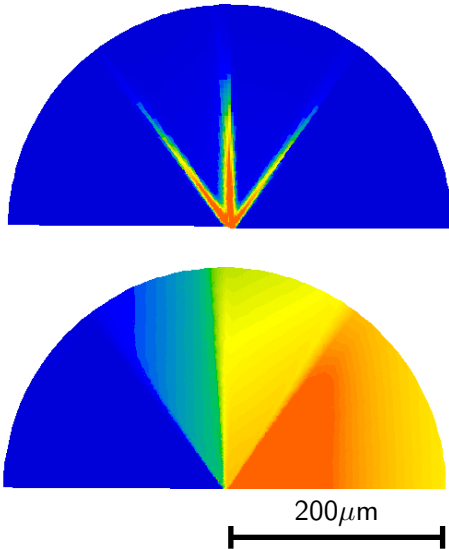


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

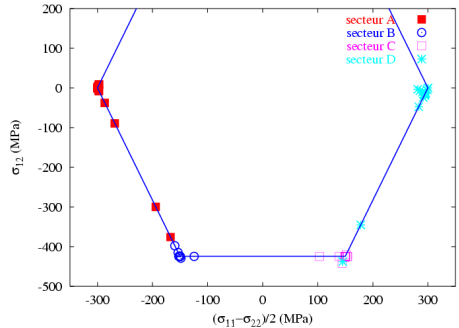
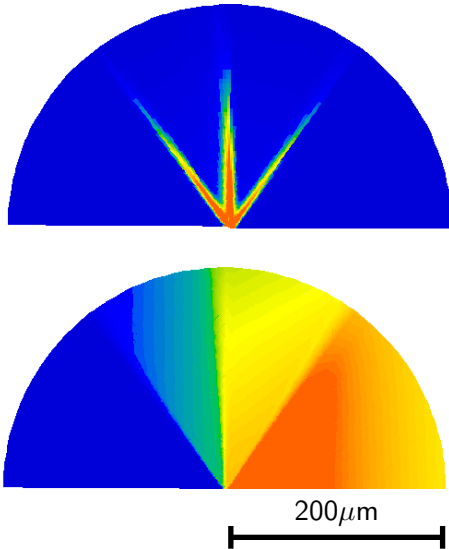


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

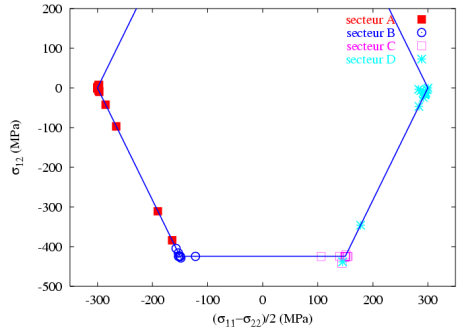
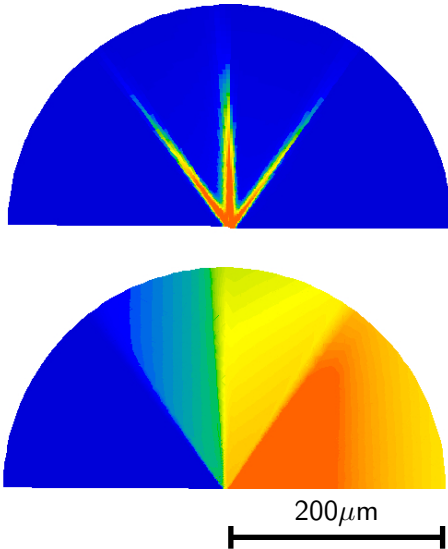


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

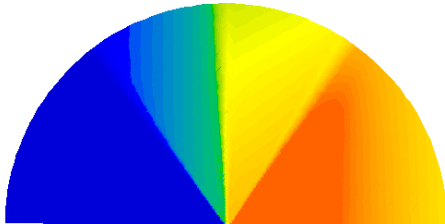
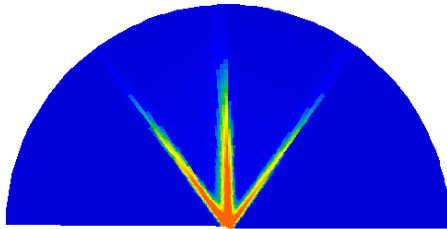


◀ Start

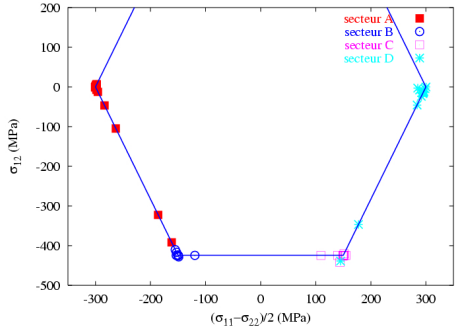
▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



200 μm

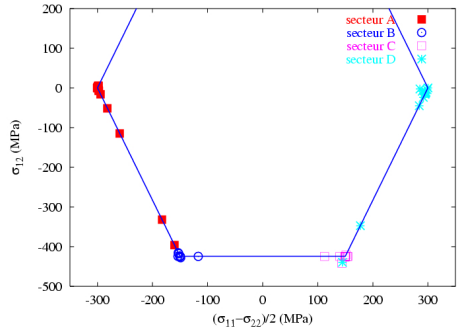
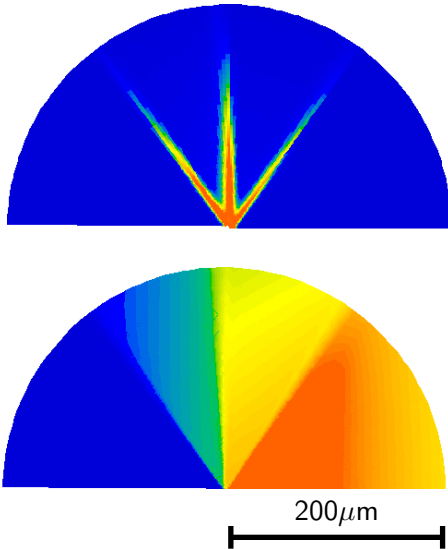


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

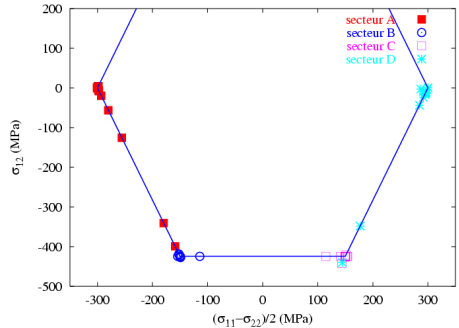
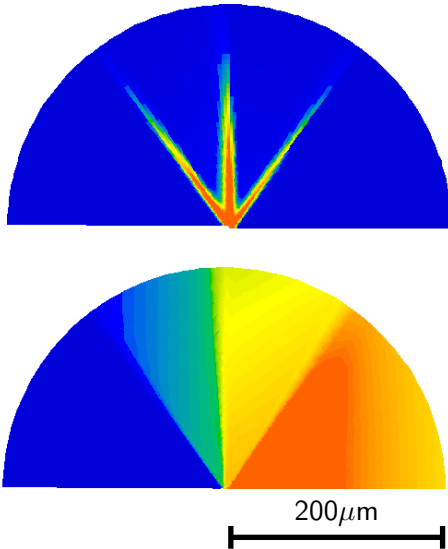


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

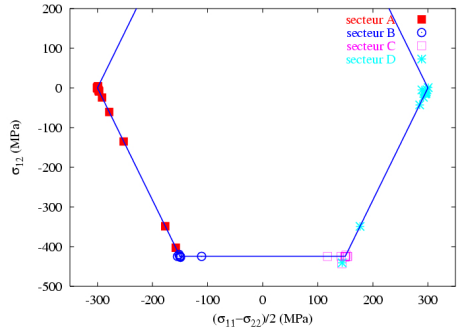
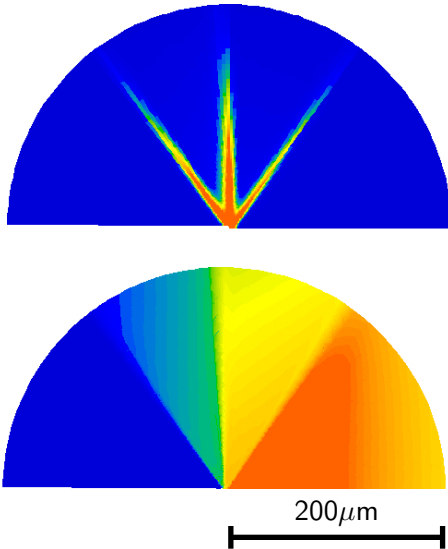


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

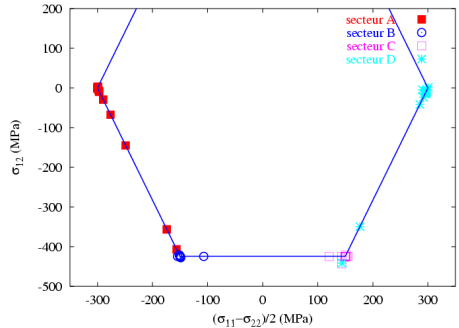
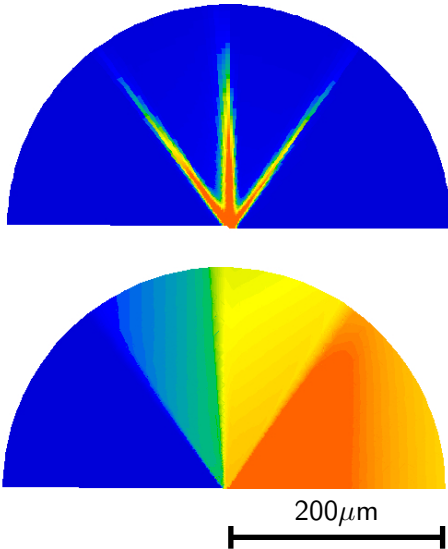


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

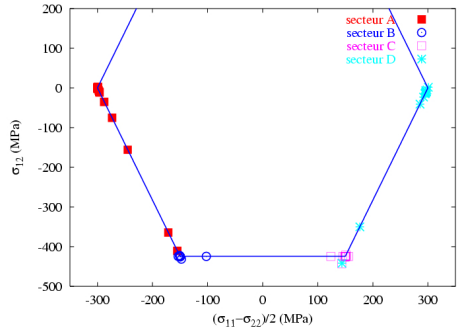
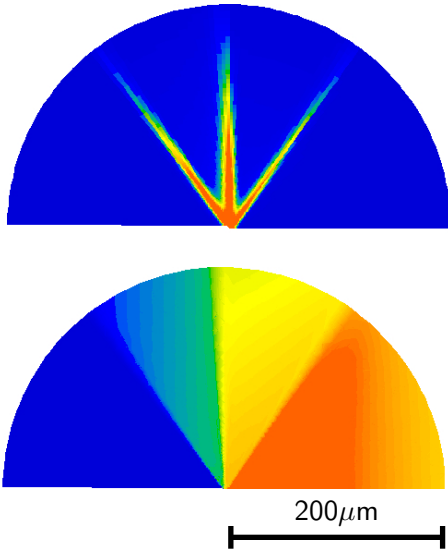


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

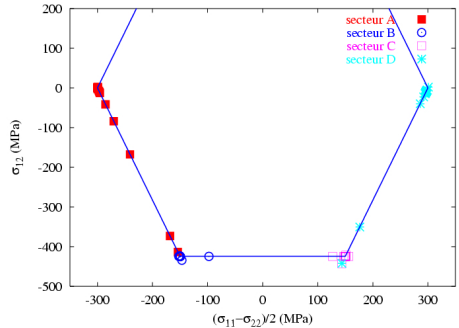
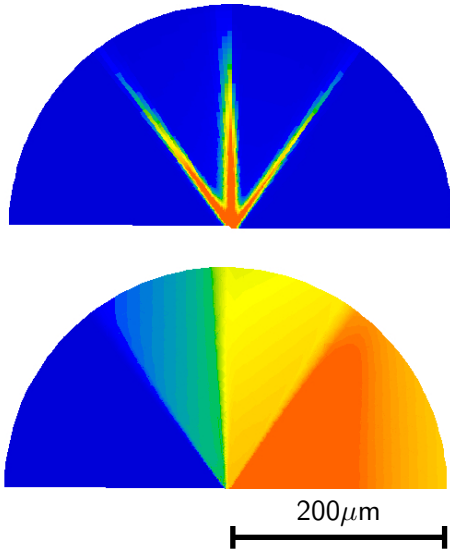


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

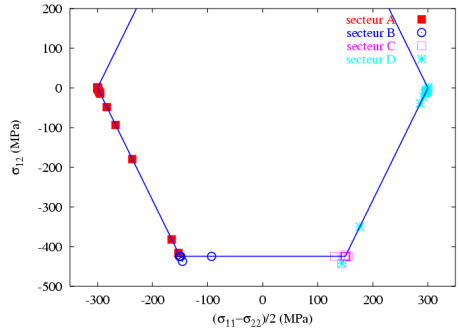
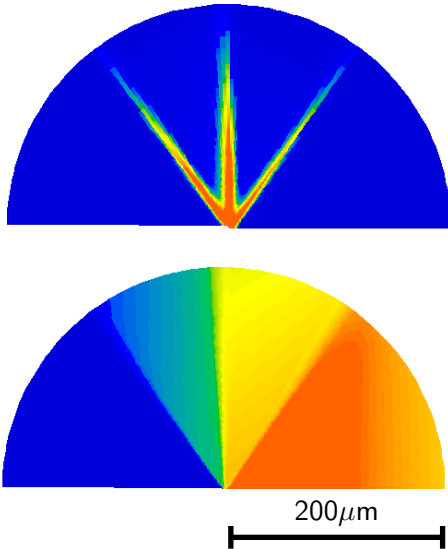


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

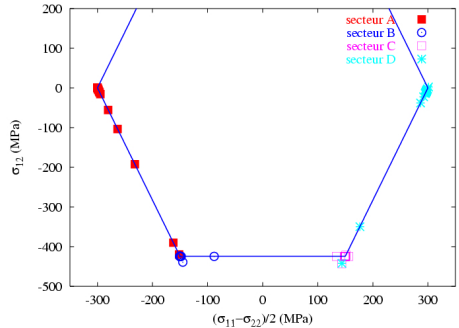
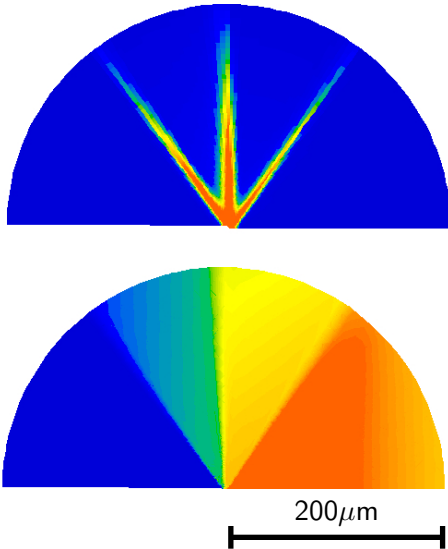


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

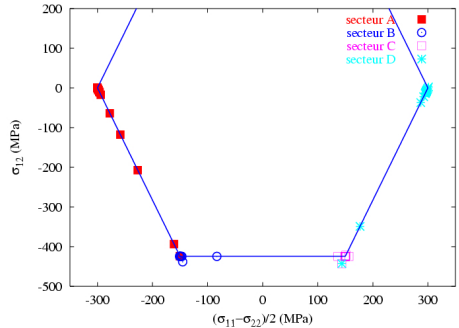
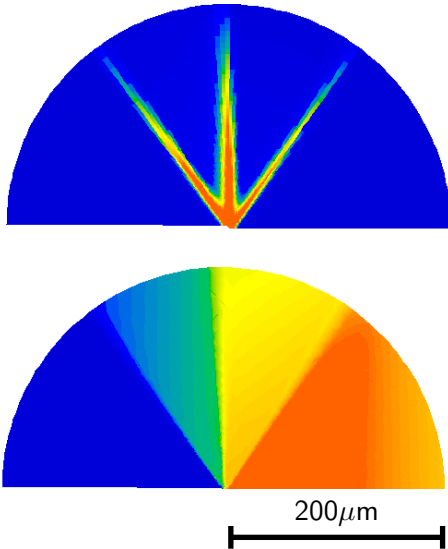


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

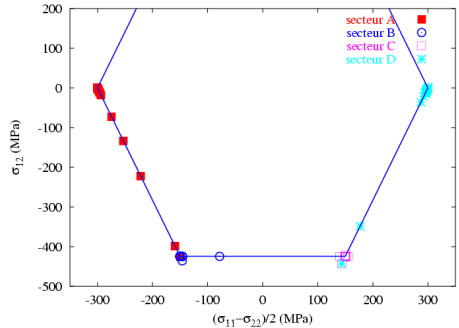
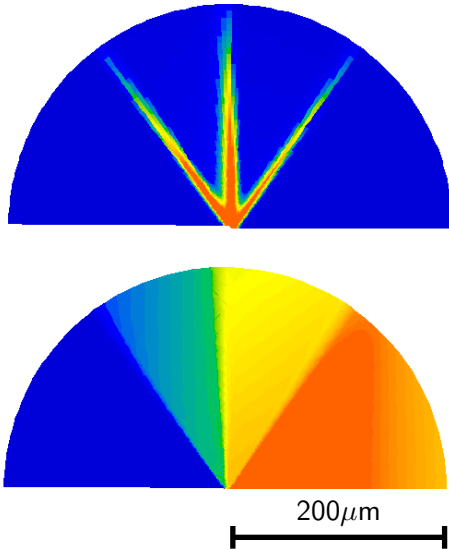


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

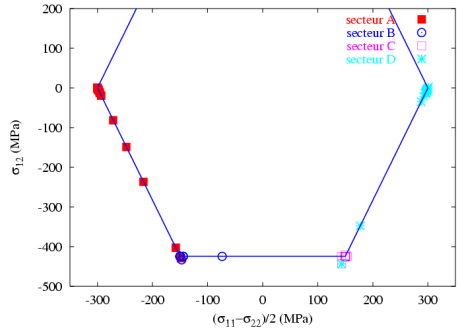
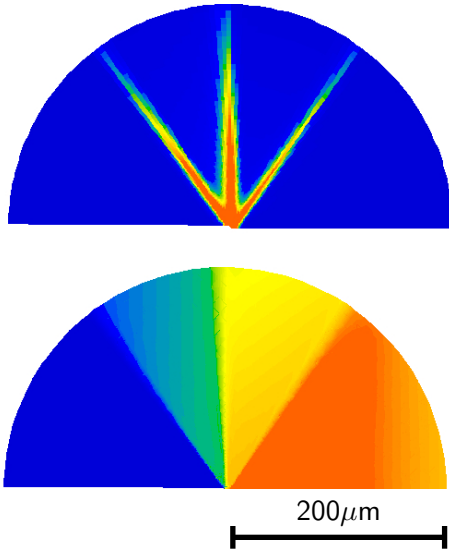


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

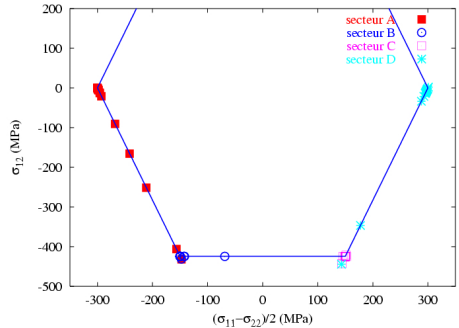
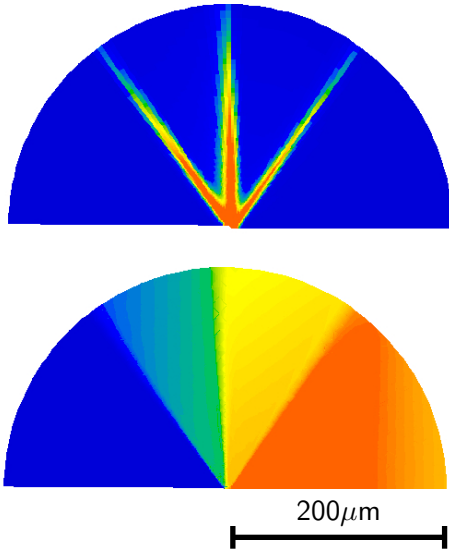


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

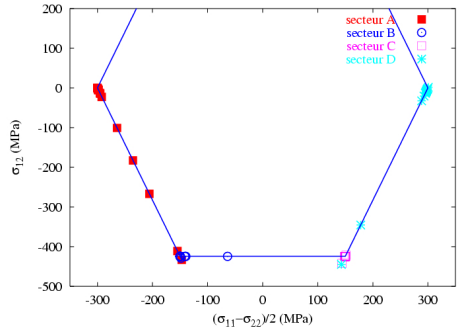
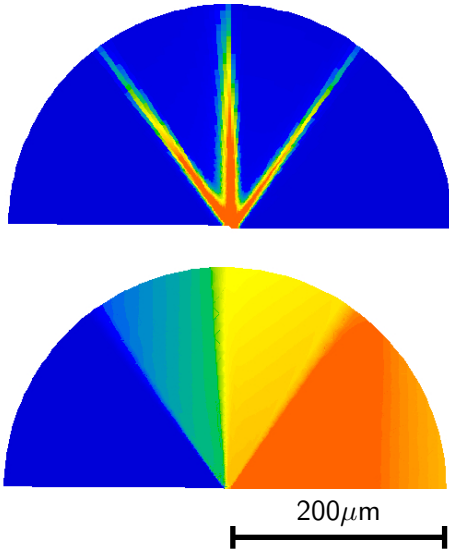


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

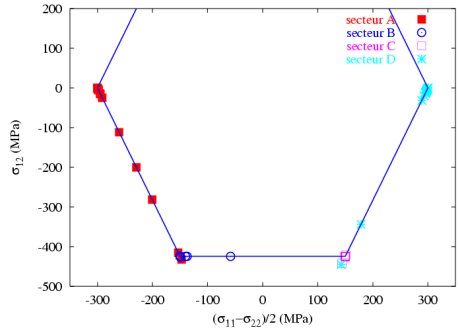
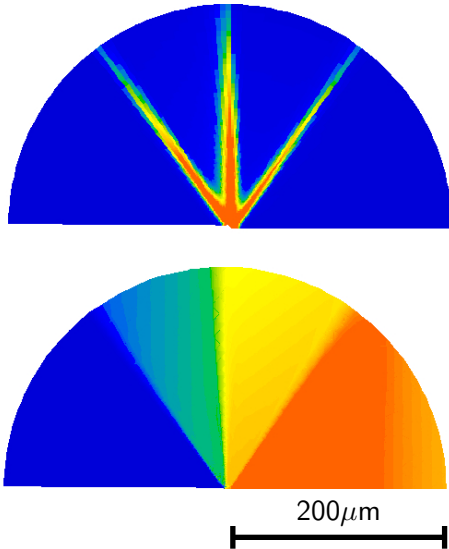


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$

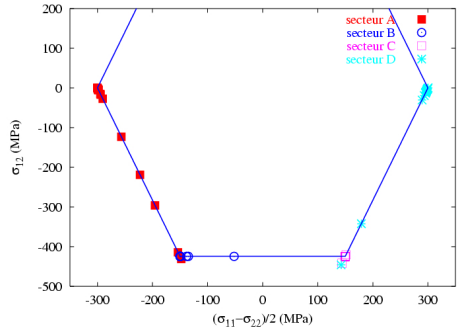
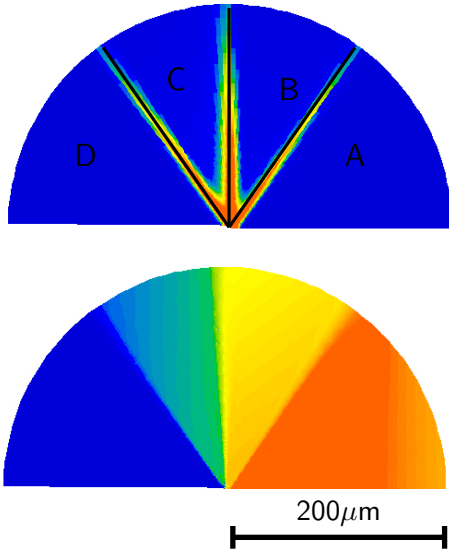


◀ Start

▶ Animation

▶ End

Finite Element analysis - Orientation $S \succ (001)[110]$



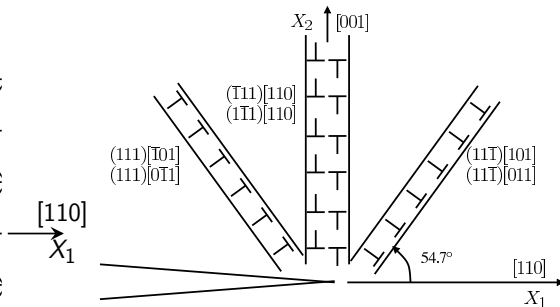
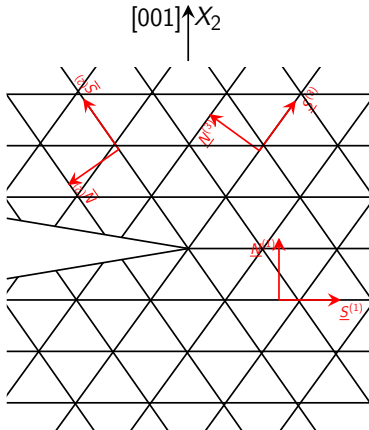
◀ Start

▶ Animation

▶ End

Structure of deformation bands - Orientation S

$\gamma(001)[110]$



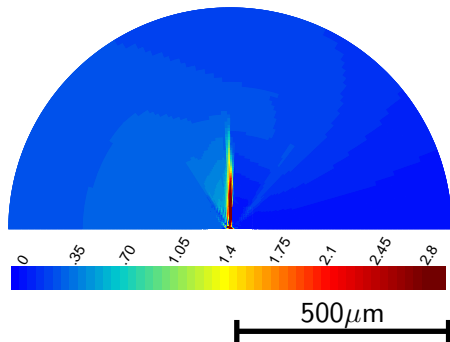
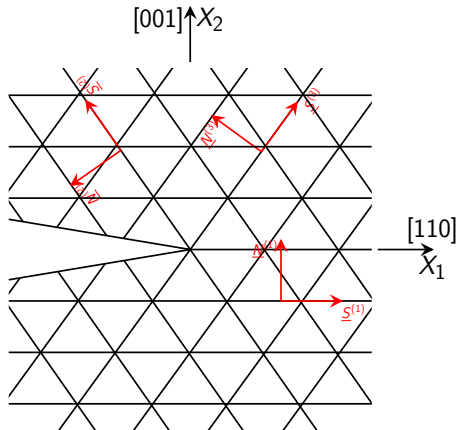
2 slip bands

1 kink band

Structure of deformation bands - Orientation S

$\gamma(001)[110]$

Rotation du réseau cristallin

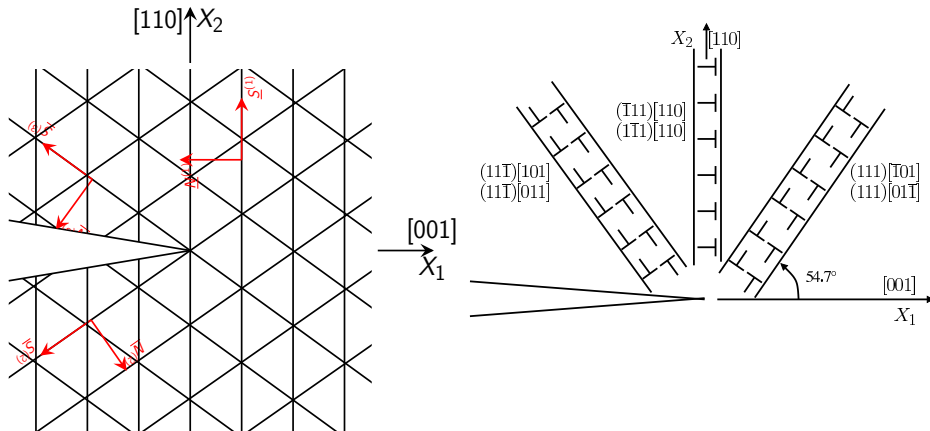


2 slip bands

1 kink band

Structure of deformation bands - Orientation K

$\gamma(110)[001]$

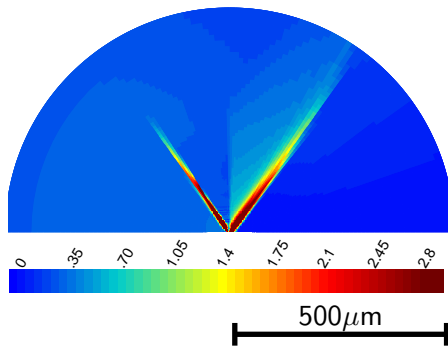
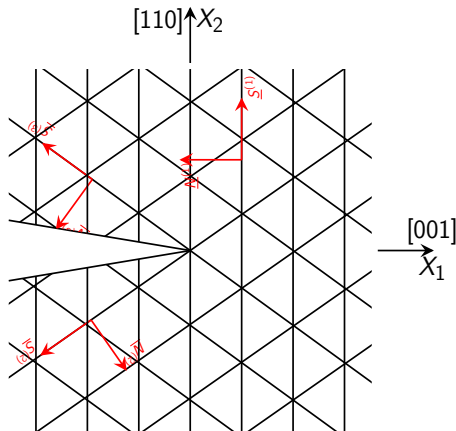


1 slip band
2 kink bands

Structure of deformation bands - Orientation K

$\gamma(110)[001]$

Rotation du réseau cristallin

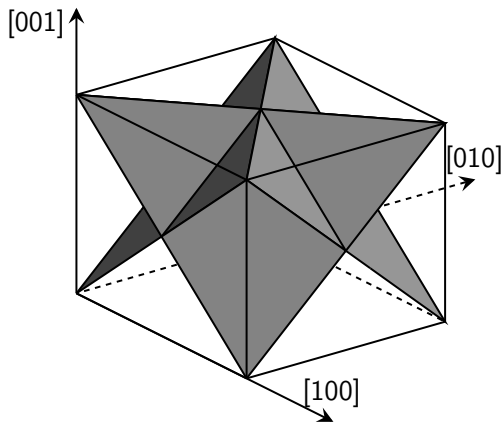


1 slip band
2 kink bands

Plan

- 1 Introduction
- 2 Rice's solution of the crack problem in SX
 - Plane strain and effective slip systems
 - Balance of momentum; field equations
 - Extension of the solutions
- 3 3D effects on the crack tip fields
 - Loading conditions
 - Comparison surface-core
- 4 Confrontation to experimental results
- 5 Application to fatigue
 - Deformation at the crack tip under cyclic loading
 - Crack propagation paths
- 6 Conclusions-perspectives

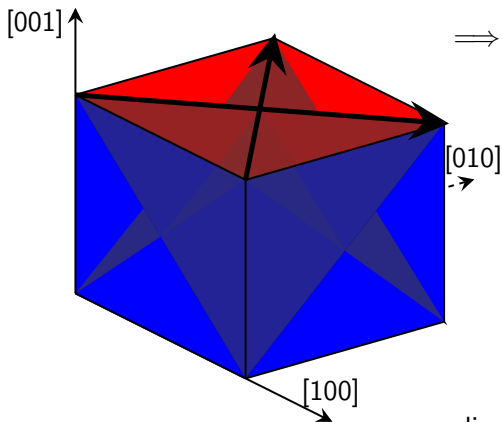
Cube slip systems



Cube slip systems

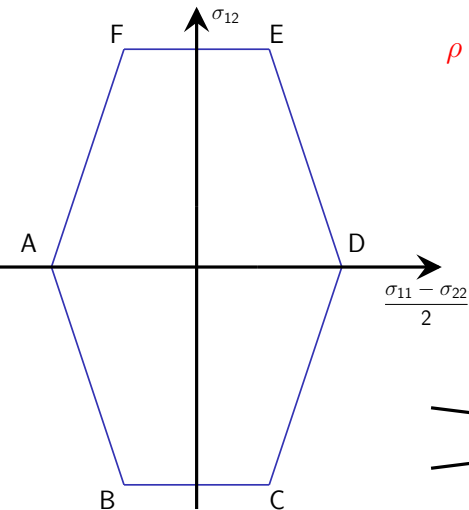
Single crystal nickel-base superalloy

⇒ cube slip systems

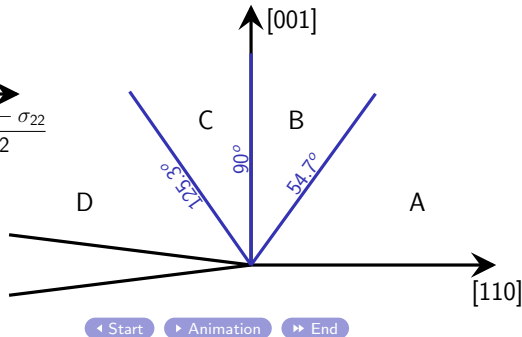


slip systems: $\{001\} \langle 110 \rangle$

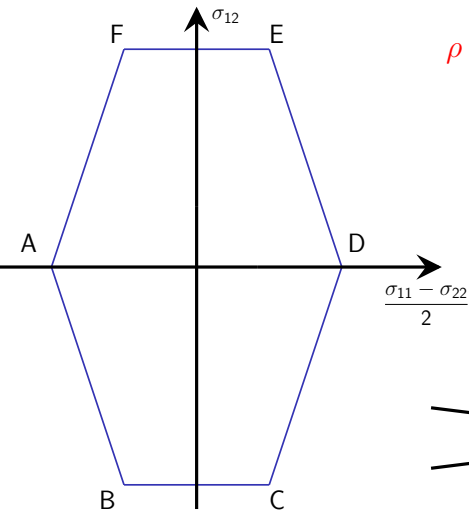
Extension to cube slip systems



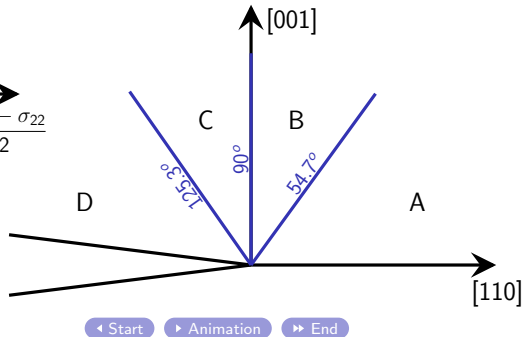
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



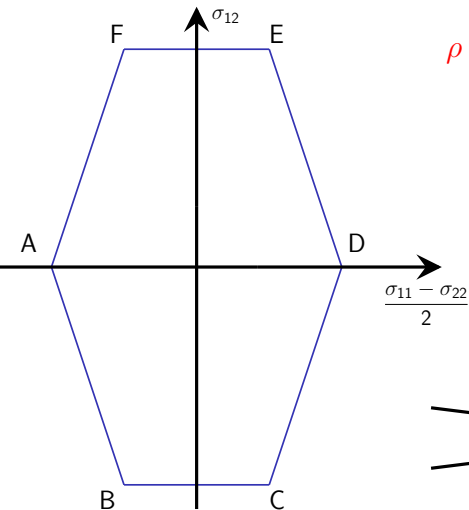
Extension to cube slip systems



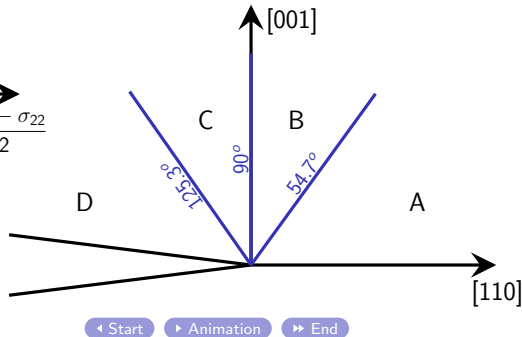
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



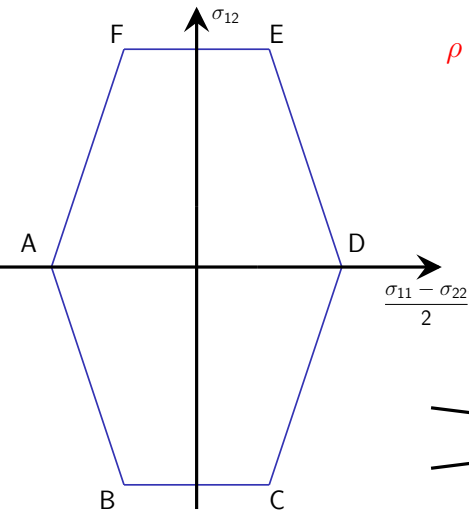
Extension to cube slip systems



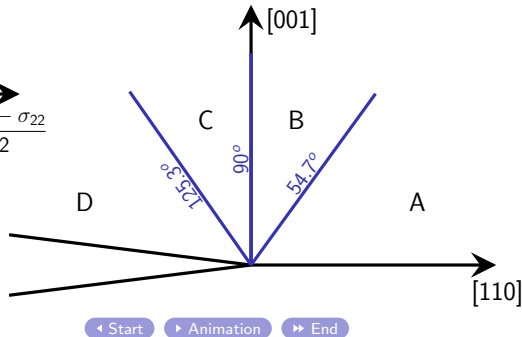
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



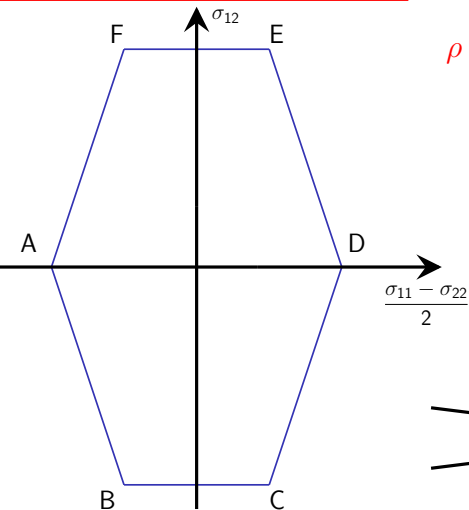
Extension to cube slip systems



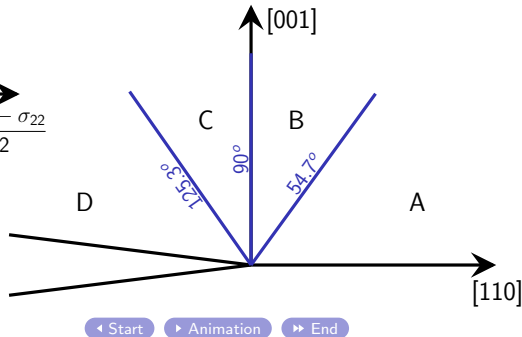
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



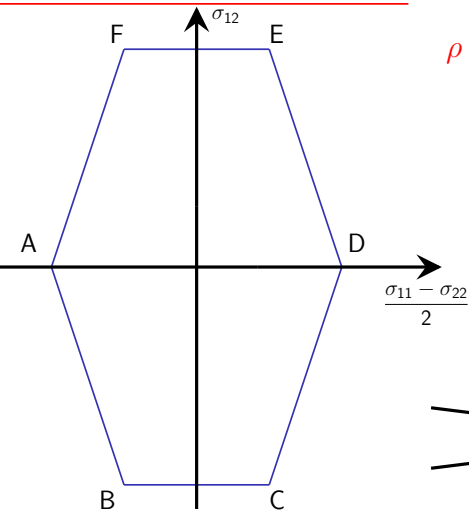
Extension to cube slip systems



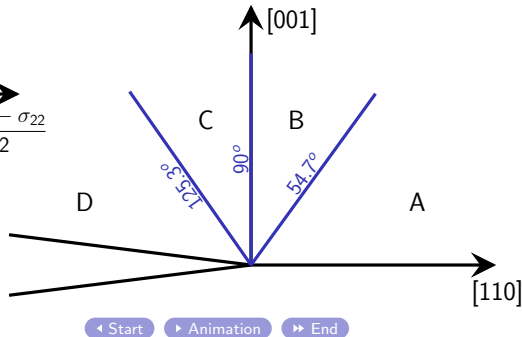
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



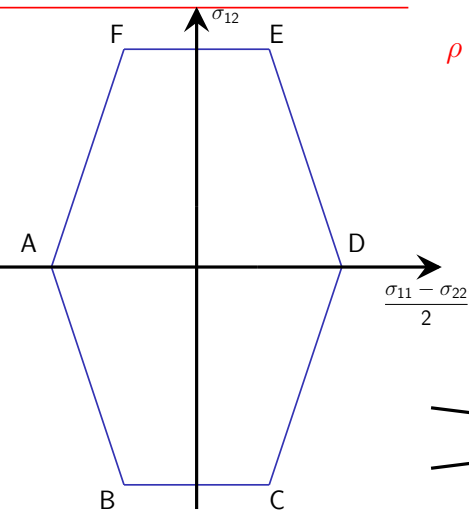
Extension to cube slip systems



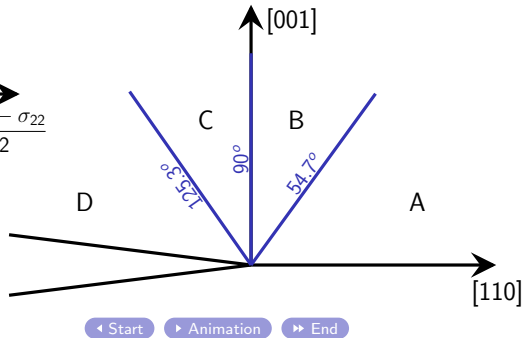
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



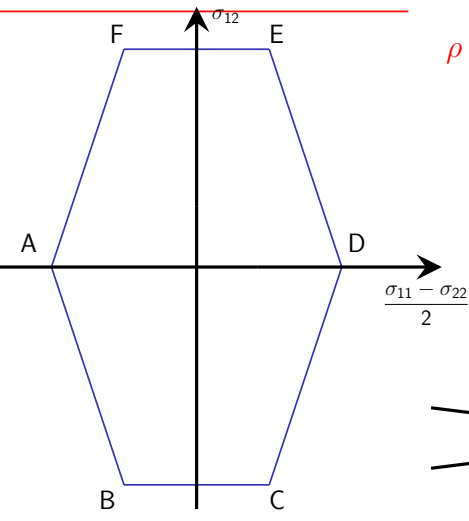
Extension to cube slip systems



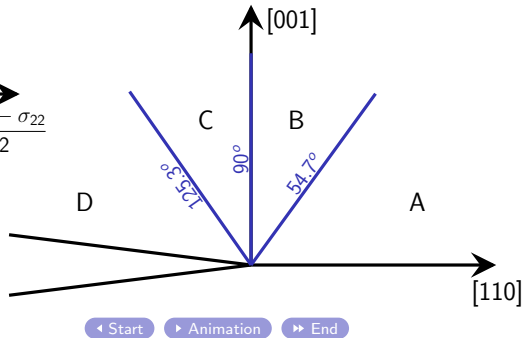
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



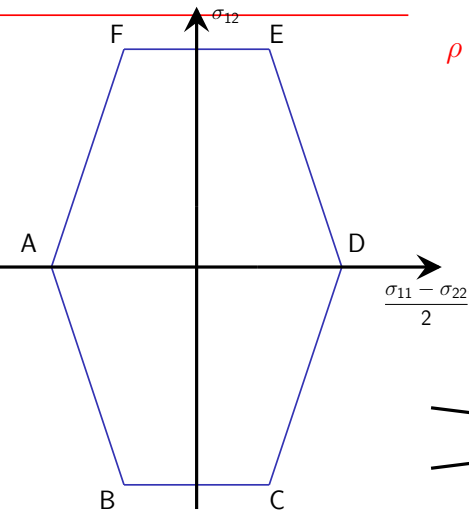
Extension to cube slip systems



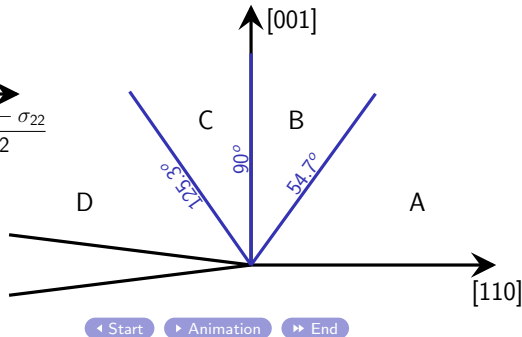
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



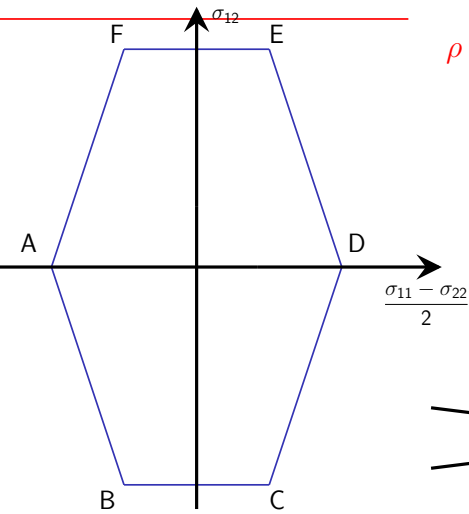
Extension to cube slip systems



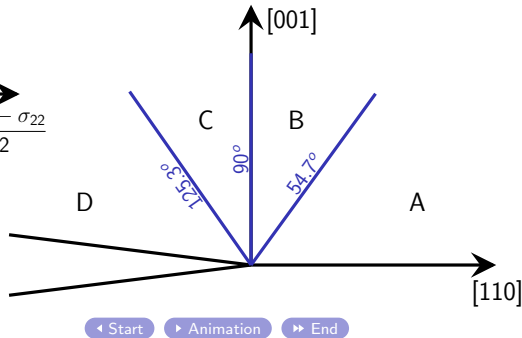
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



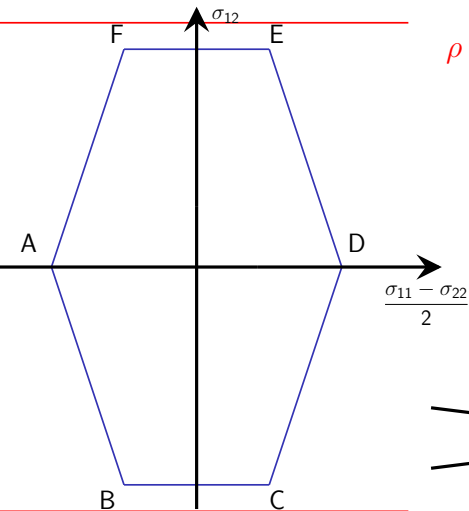
Extension to cube slip systems



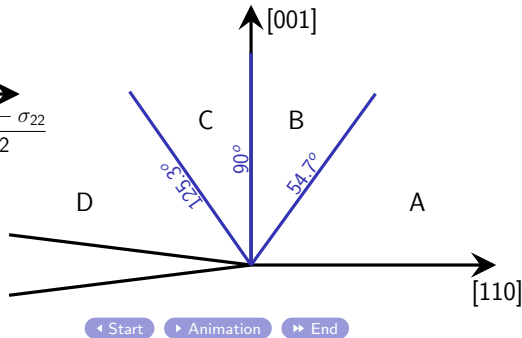
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



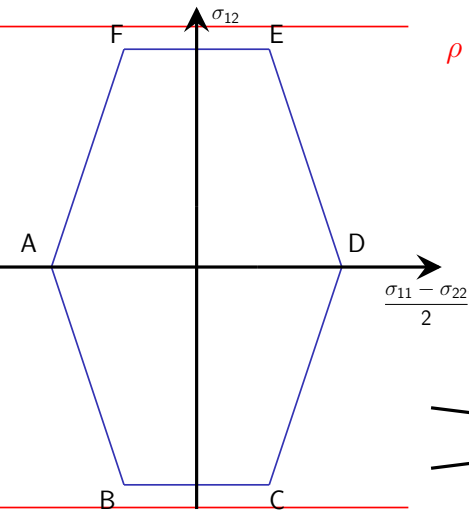
Extension to cube slip systems



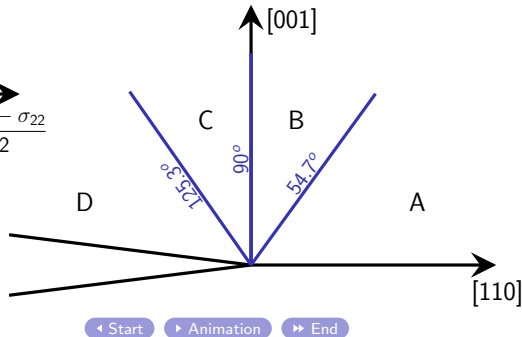
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



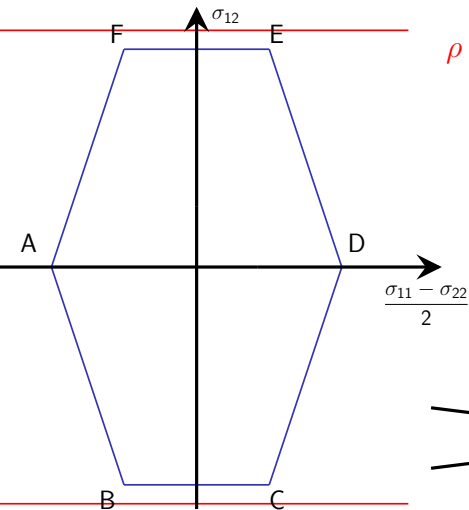
Extension to cube slip systems



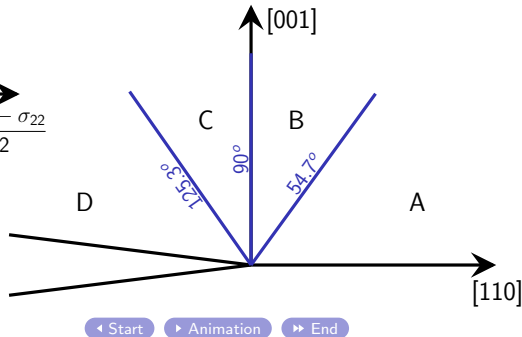
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



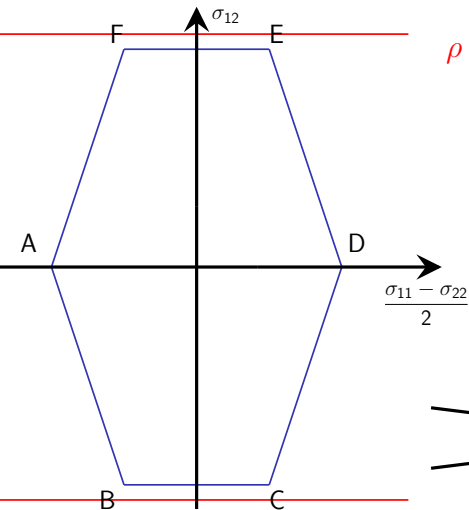
Extension to cube slip systems



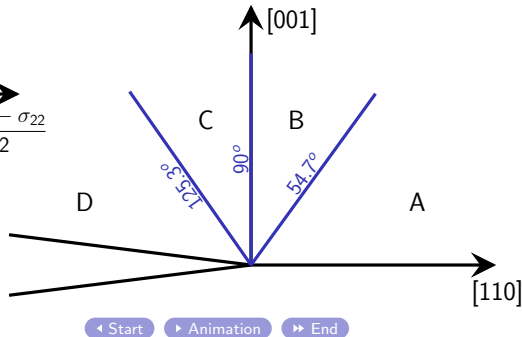
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



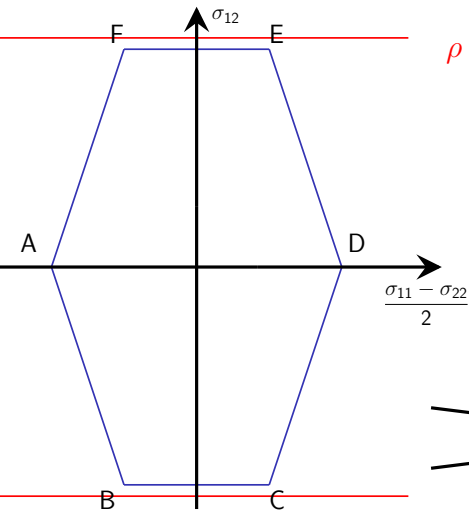
Extension to cube slip systems



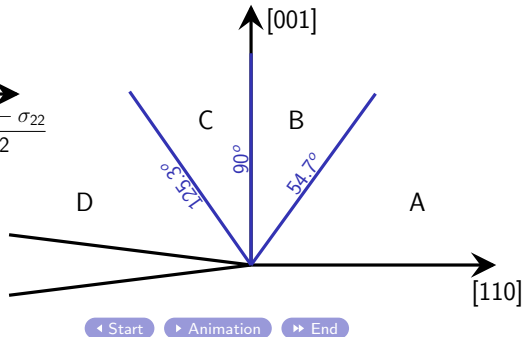
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



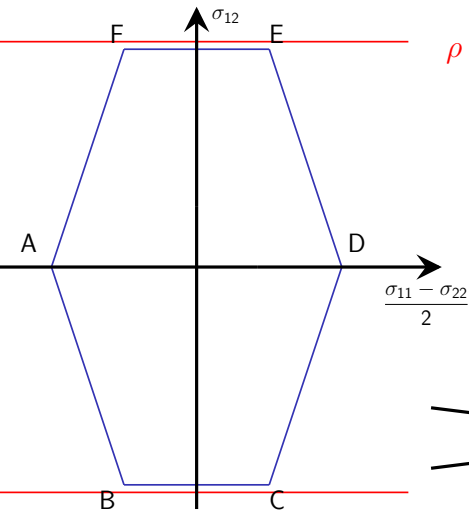
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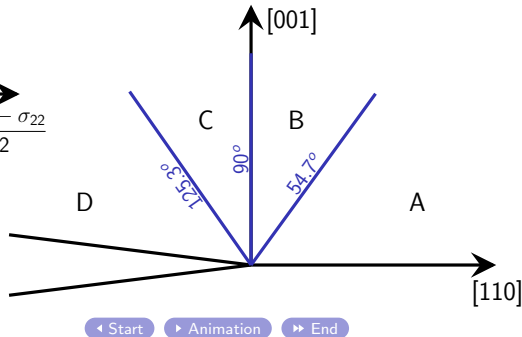
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



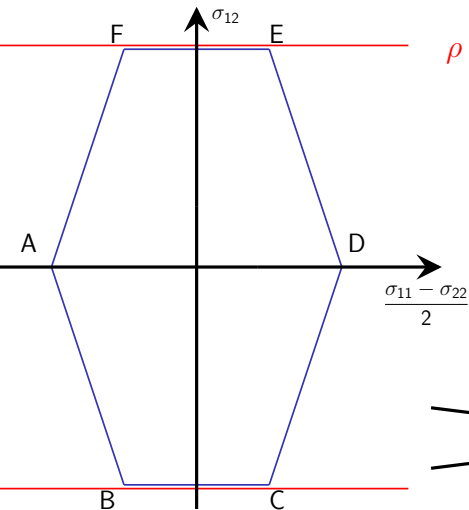
Extension to cube slip systems



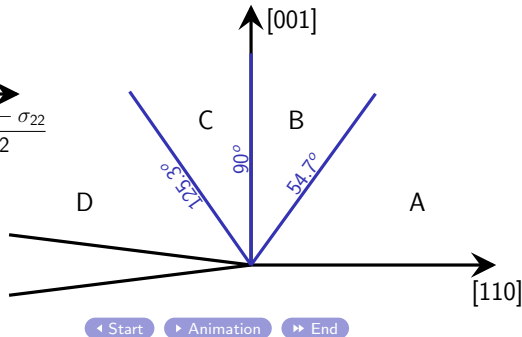
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



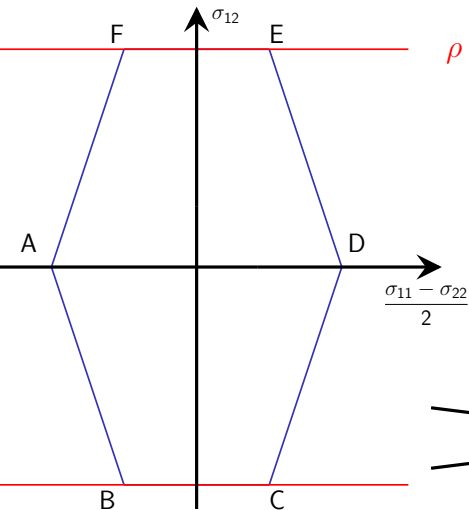
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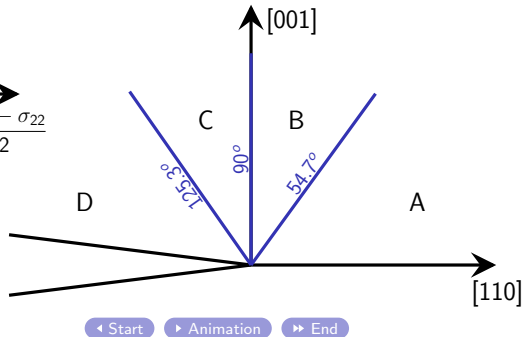
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



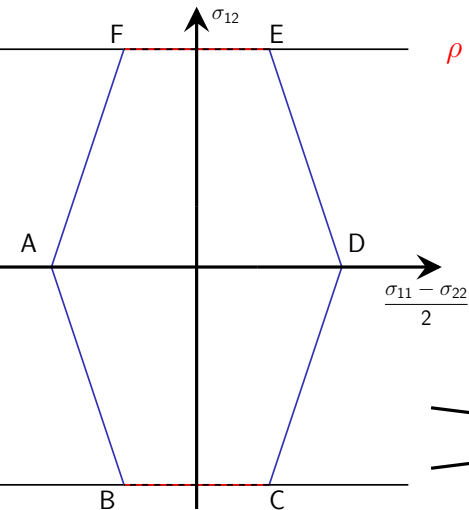
Extension to cube slip systems



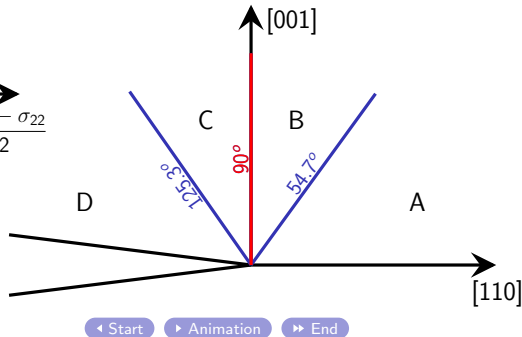
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



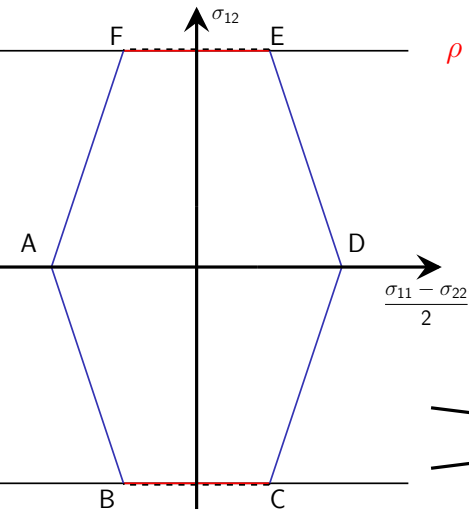
Extension to cube slip systems



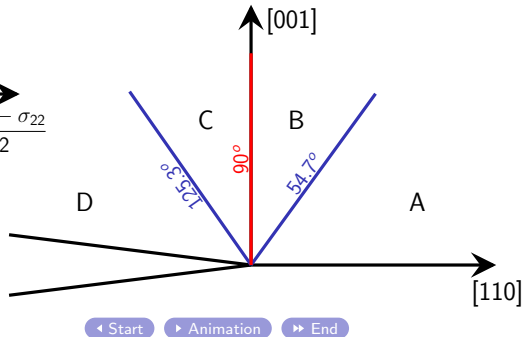
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



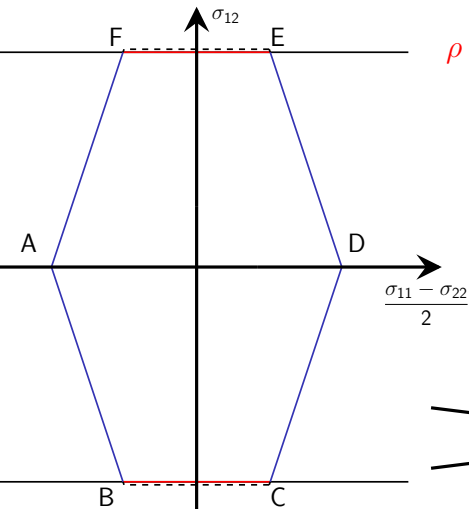
Extension to cube slip systems



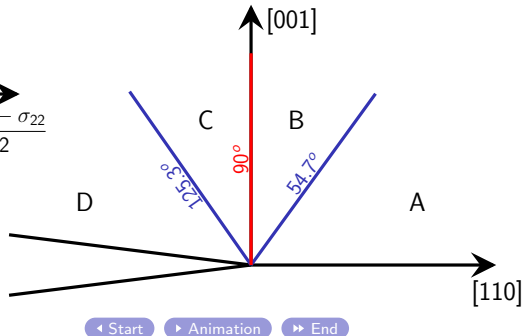
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



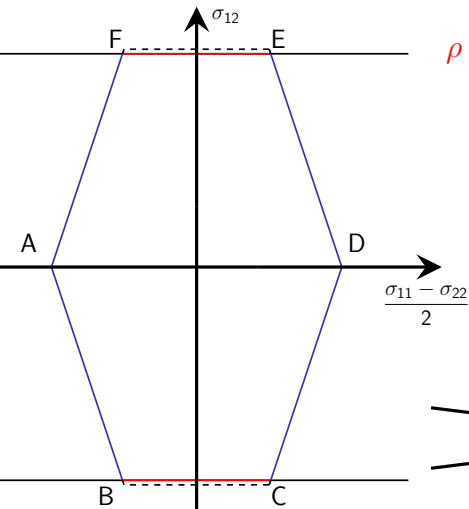
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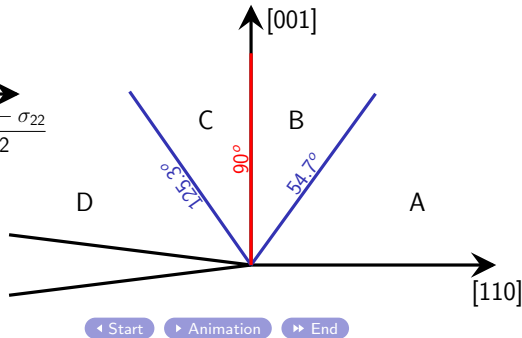
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



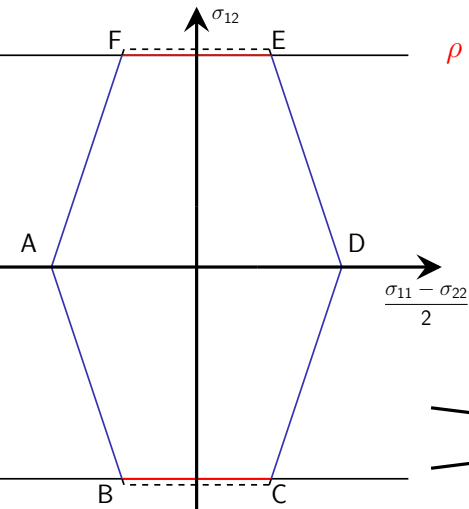
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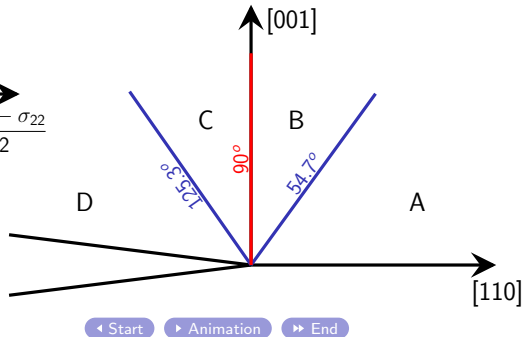
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



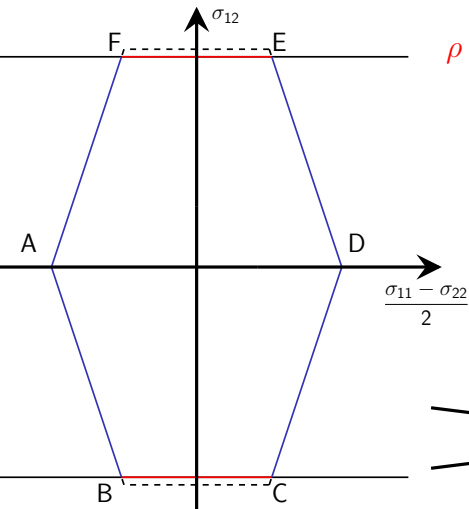
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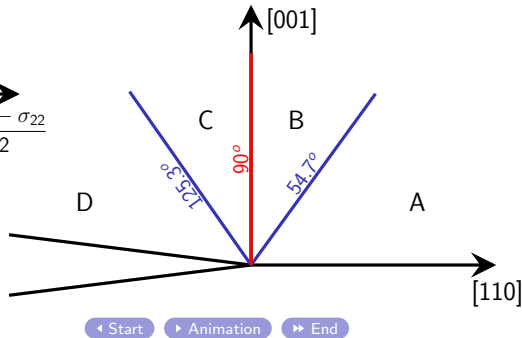
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



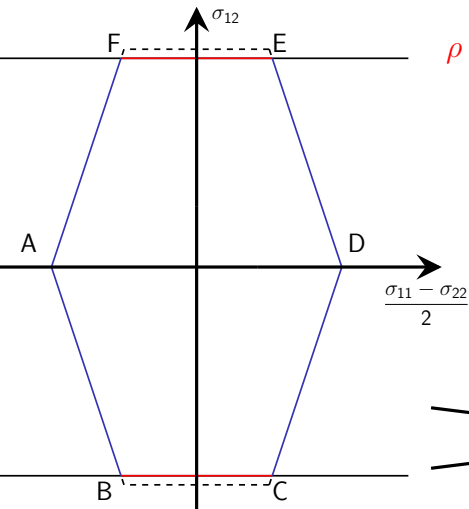
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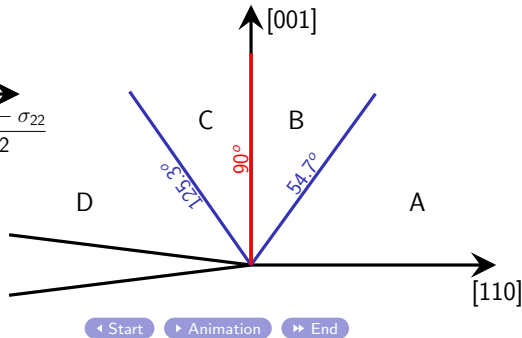
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



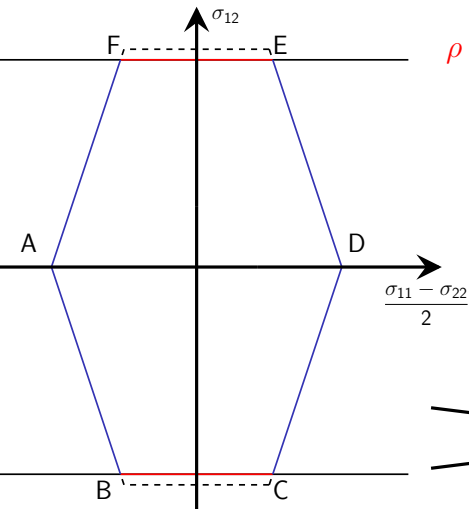
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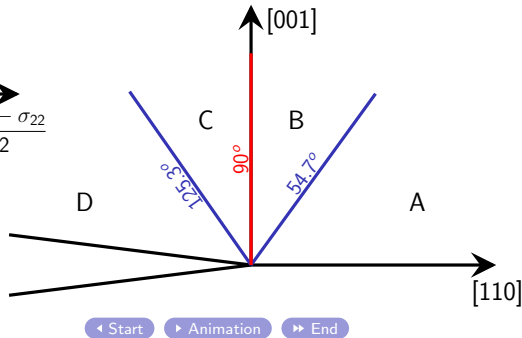
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



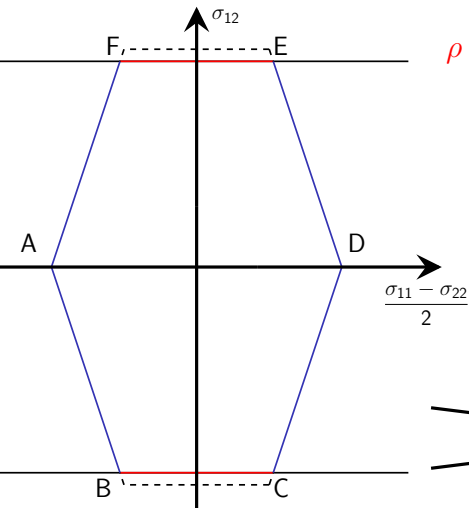
Extension to cube slip systems



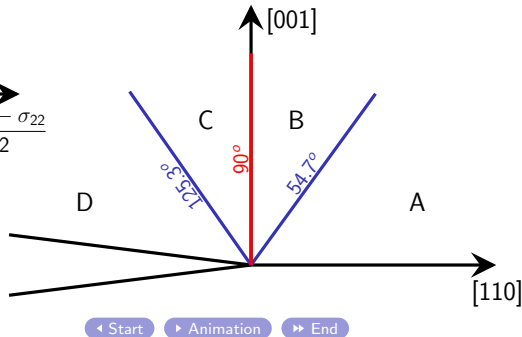
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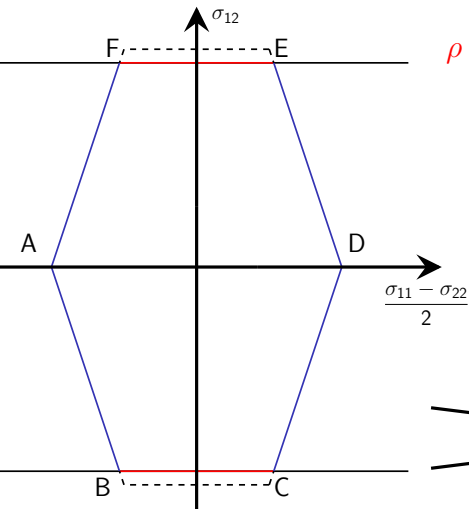
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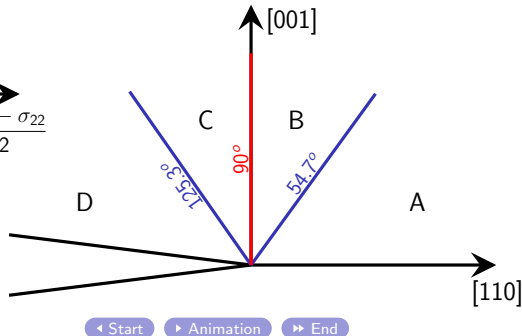
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Extension to cube slip systems



$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$

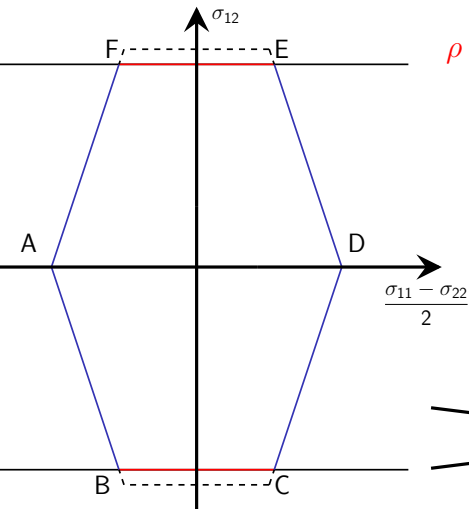


◀ Start

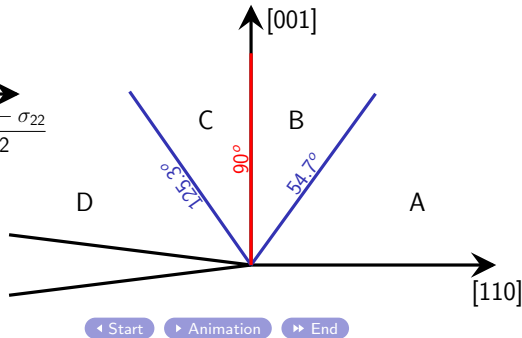
▶ Animation

▶▶ End

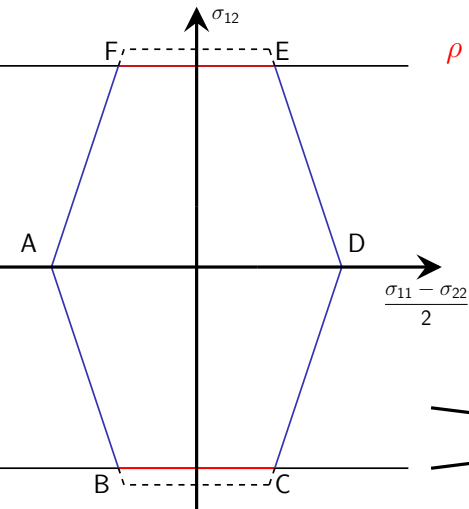
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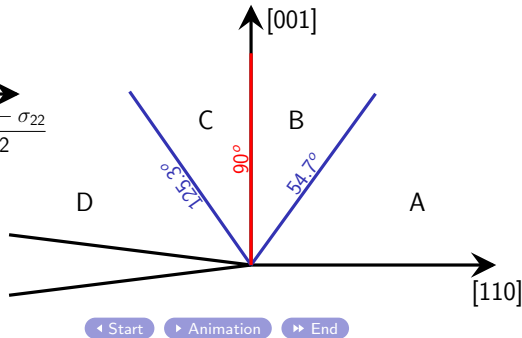
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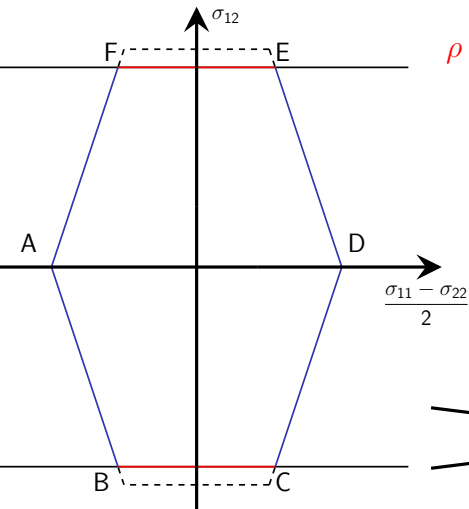
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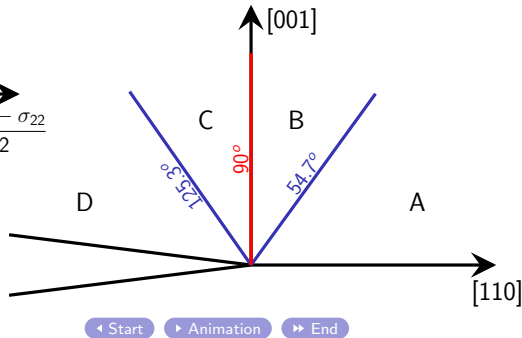
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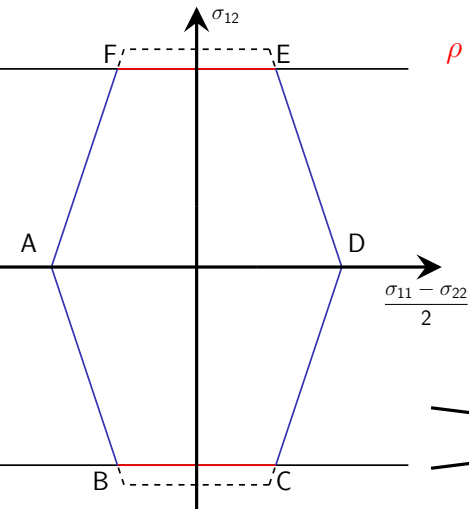
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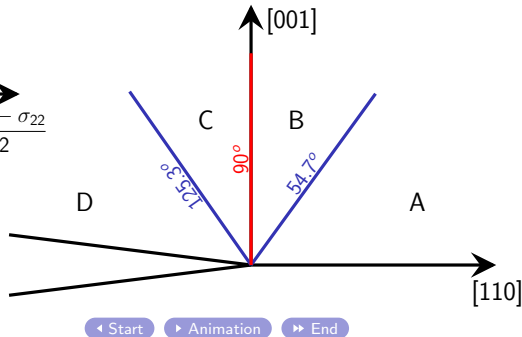
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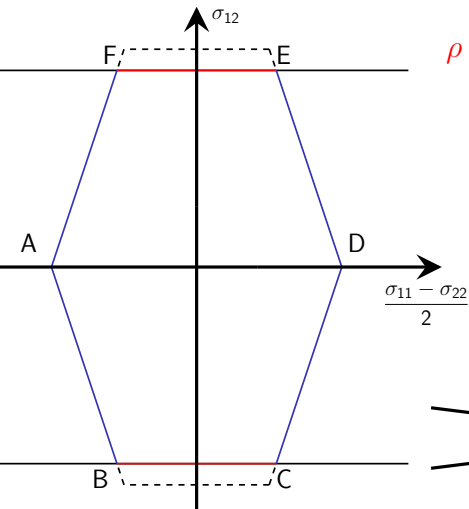
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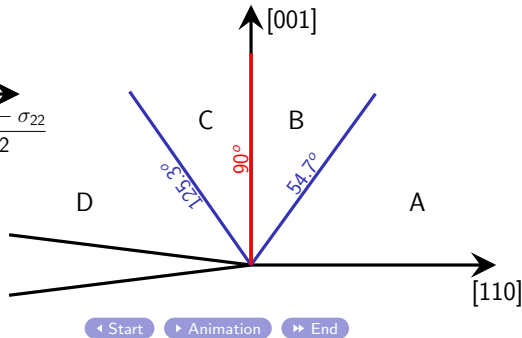
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



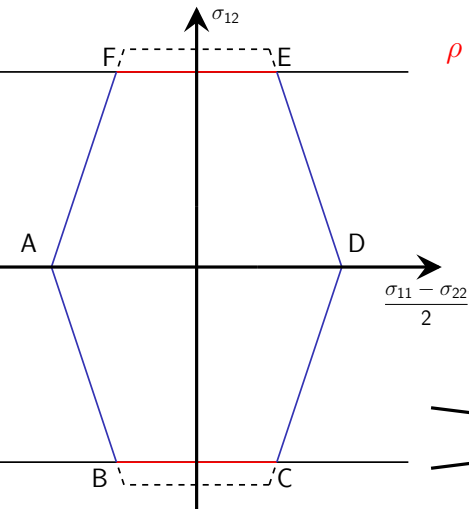
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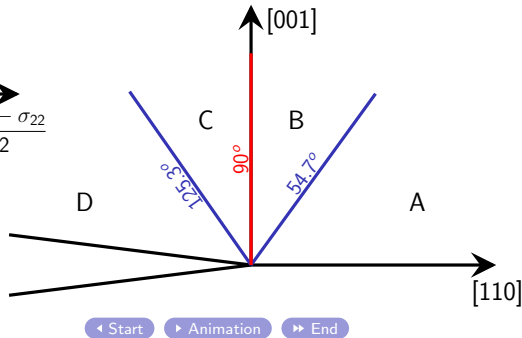
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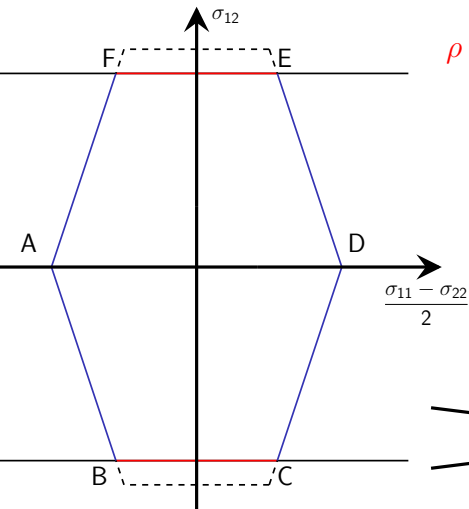
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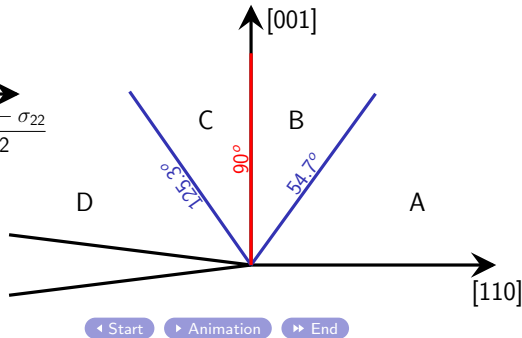
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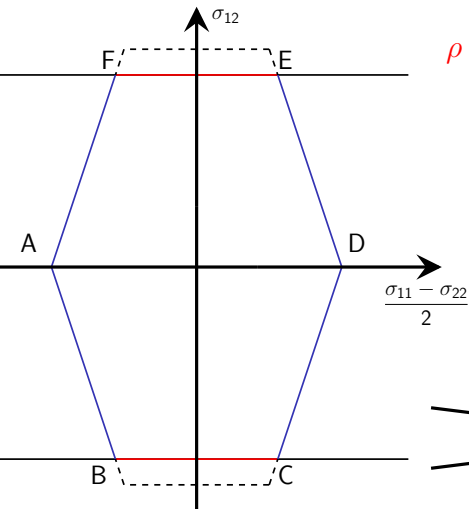
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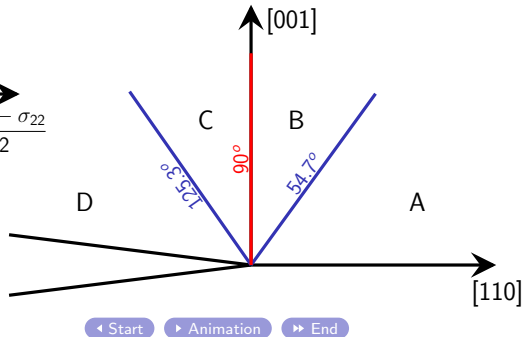
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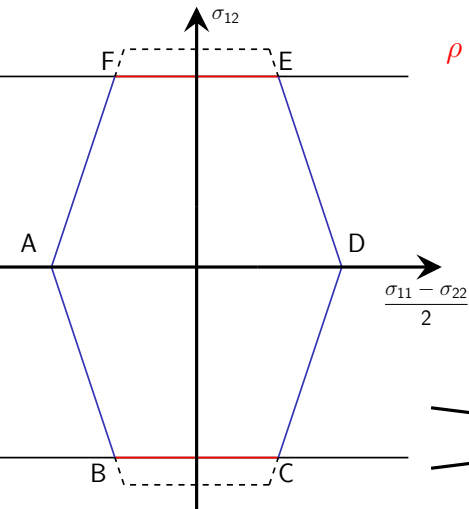
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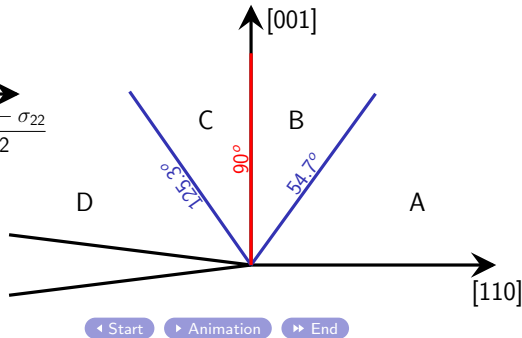
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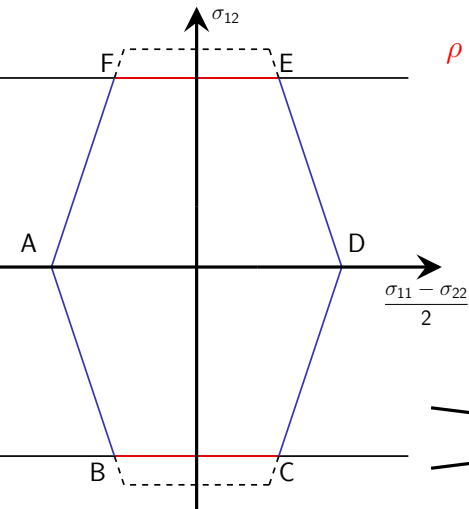
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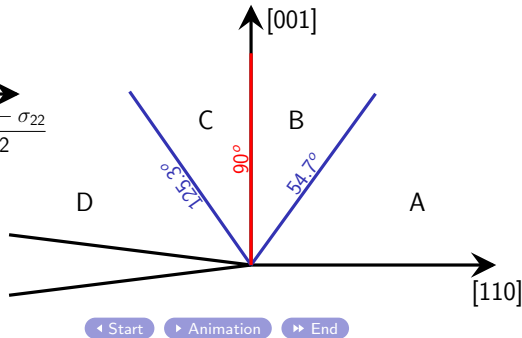
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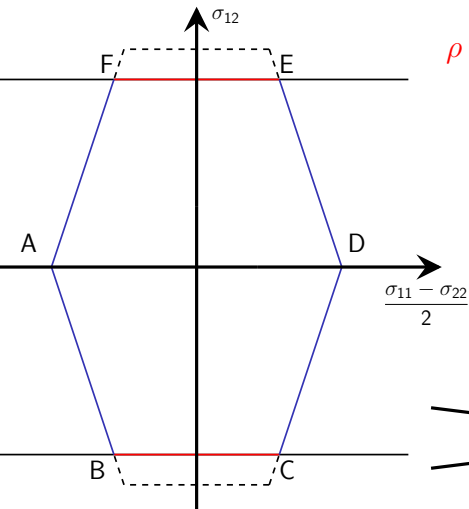
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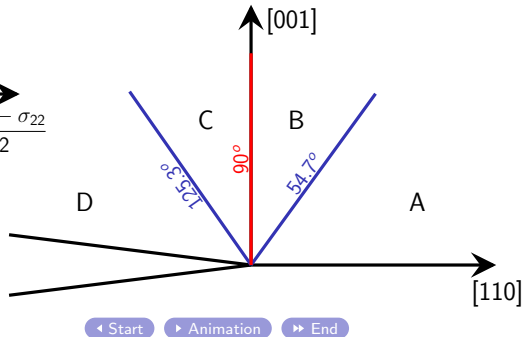
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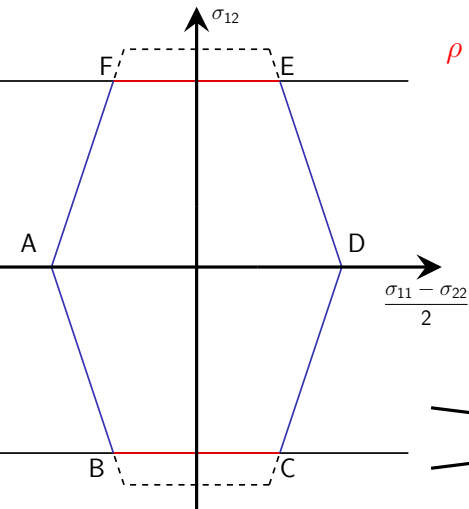
Extension to cube slip systems



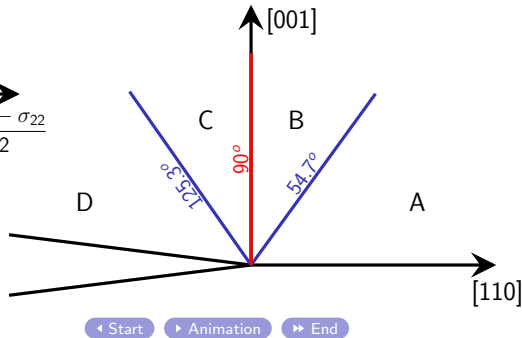
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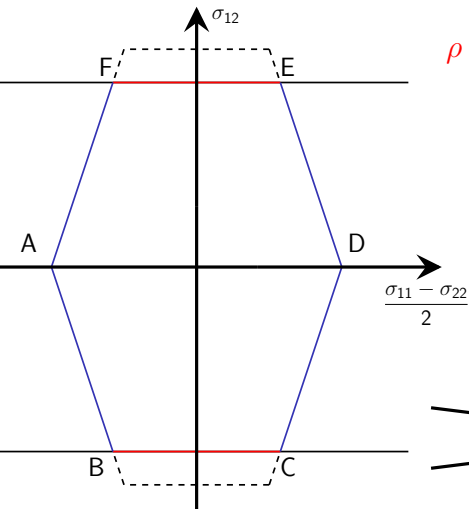
Extension to cube slip systems



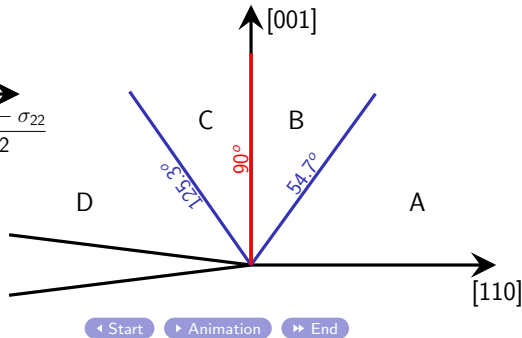
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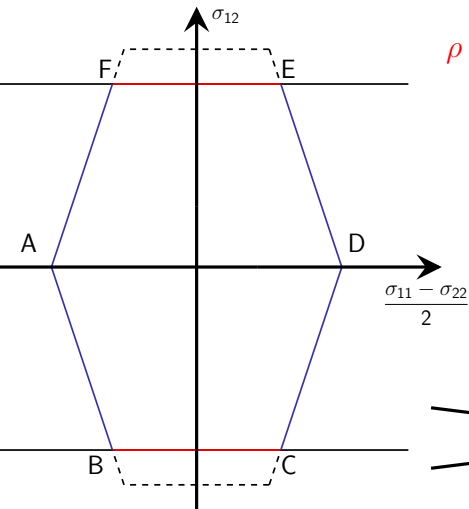
Extension to cube slip systems



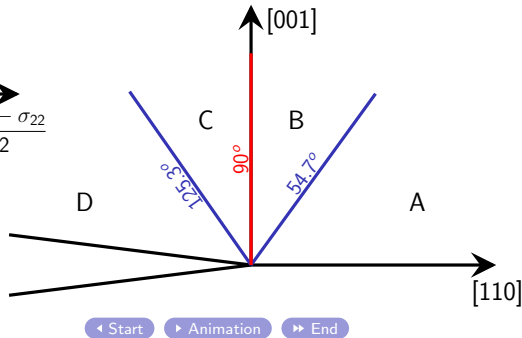
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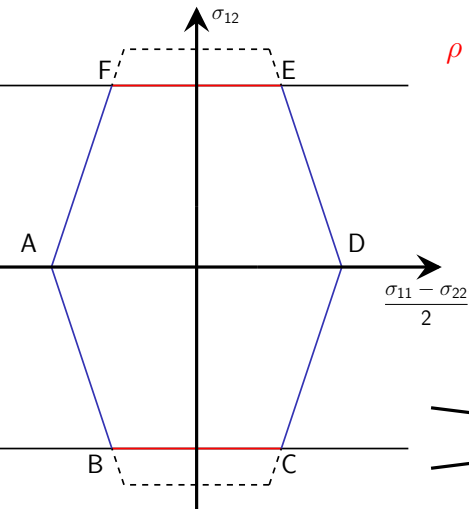
Extension to cube slip systems



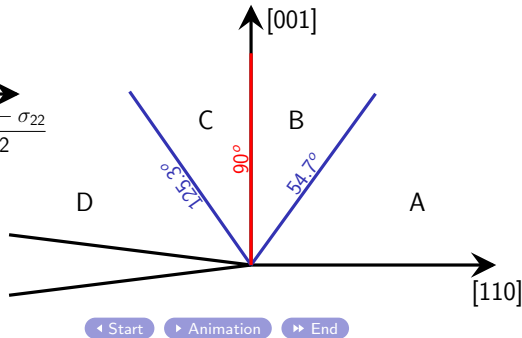
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



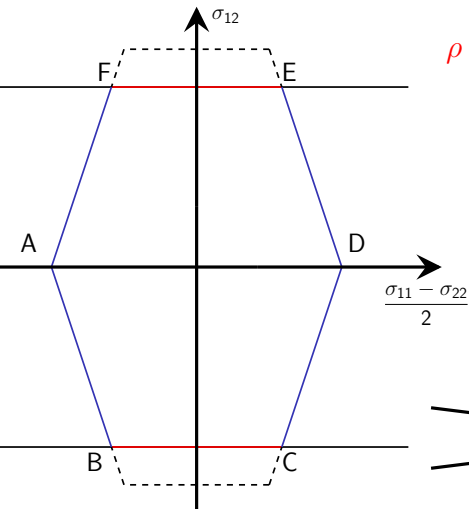
Extension to cube slip systems



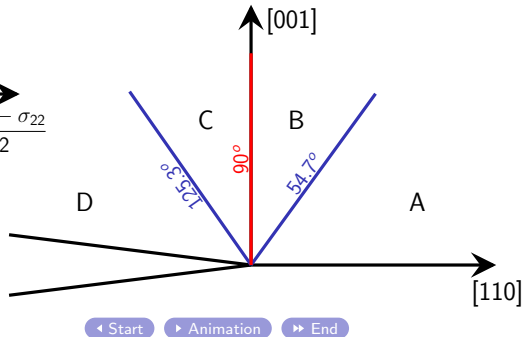
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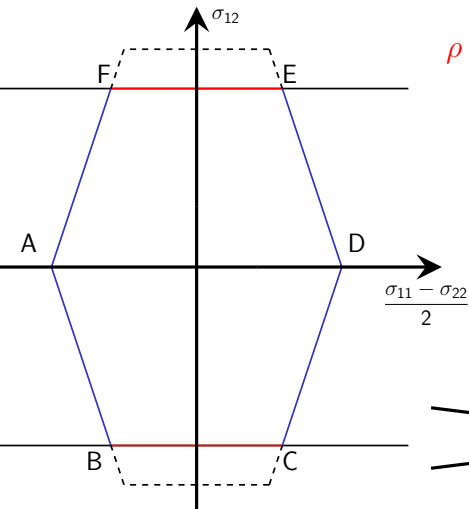
Extension to cube slip systems



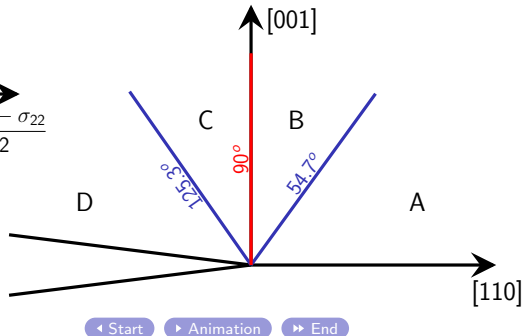
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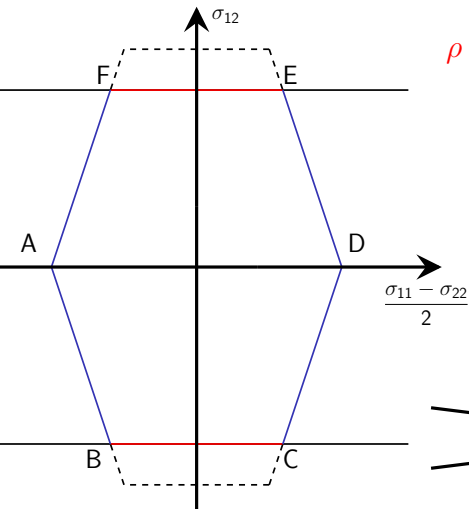
Extension to cube slip systems



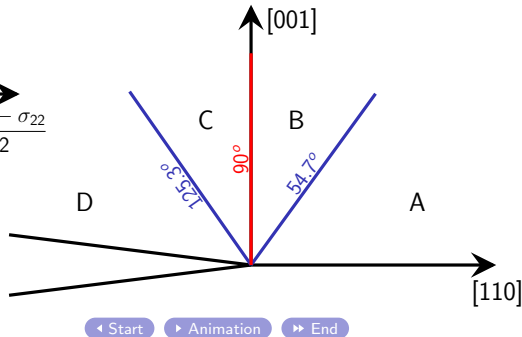
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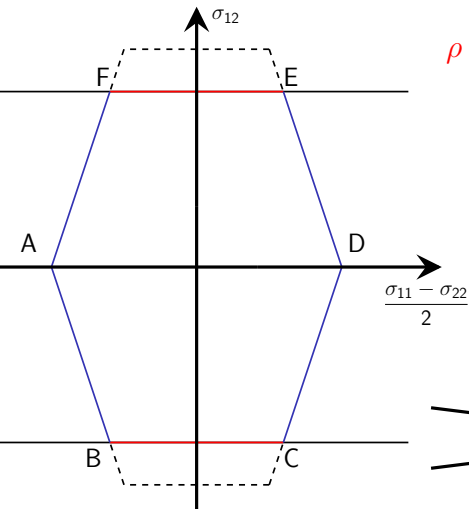
Extension to cube slip systems



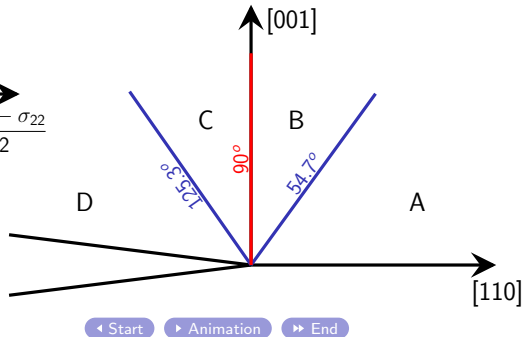
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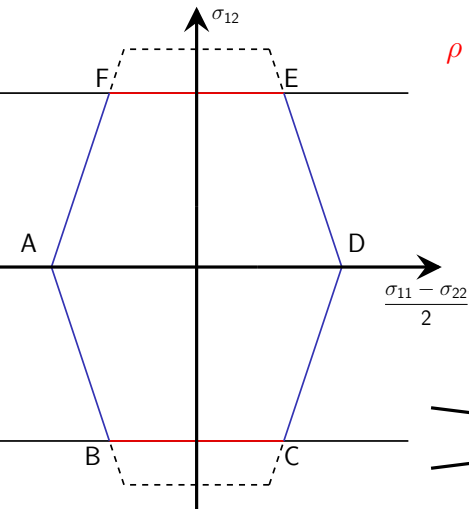
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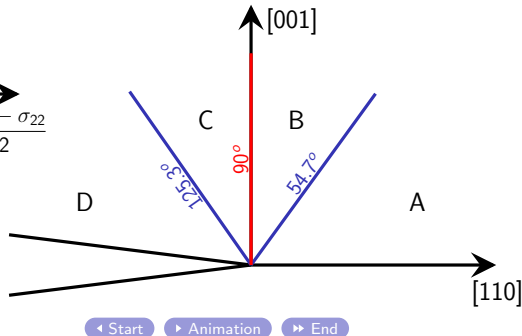
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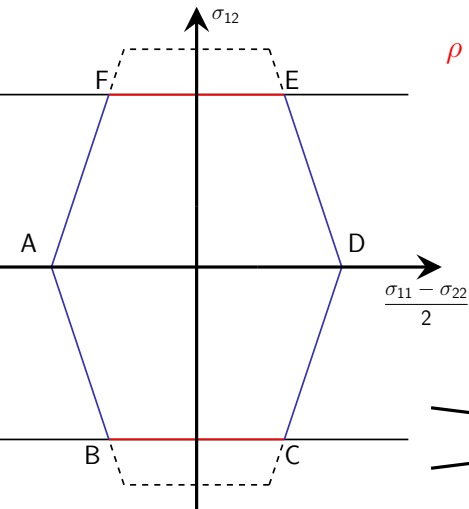
Extension to cube slip systems



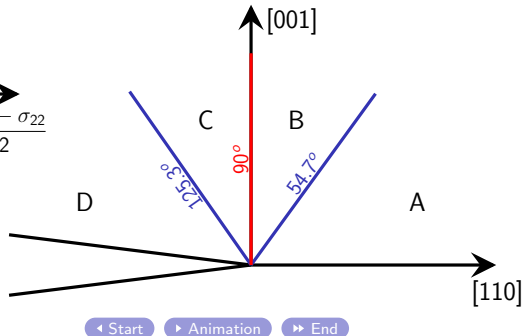
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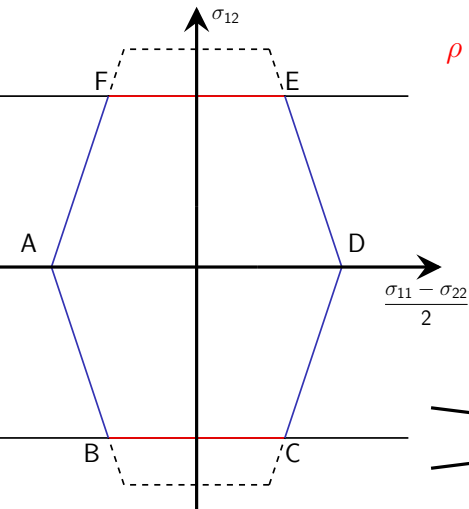
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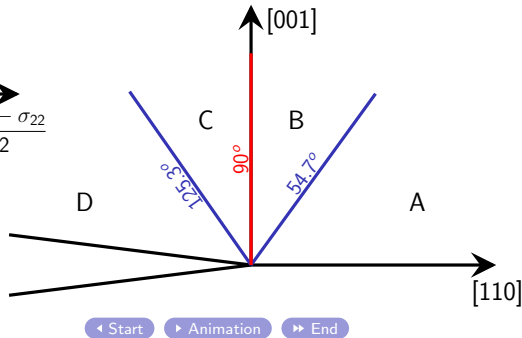
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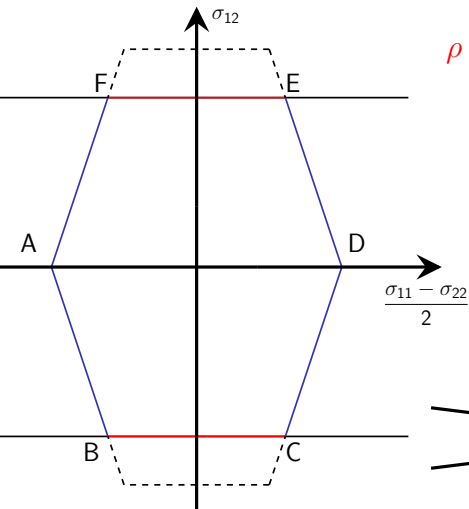
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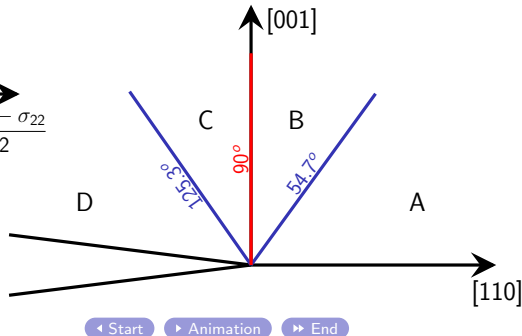
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



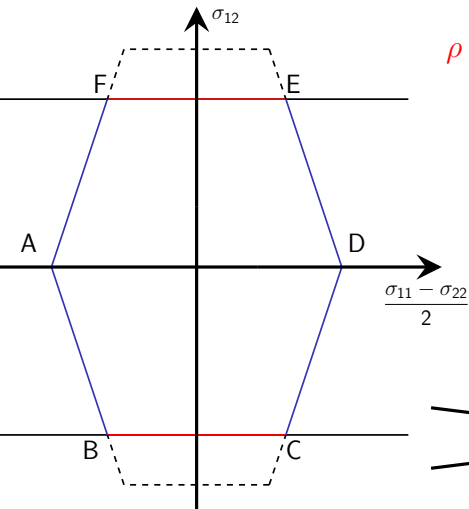
Extension to cube slip systems



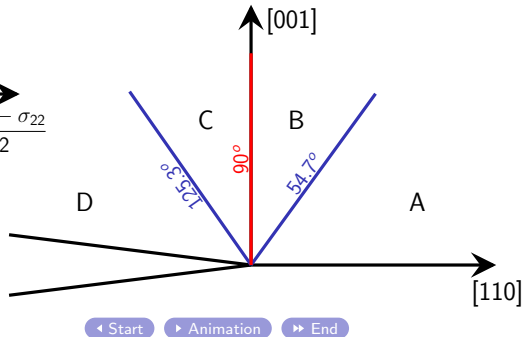
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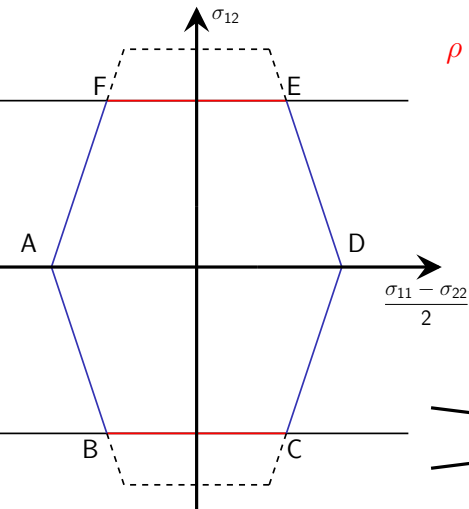
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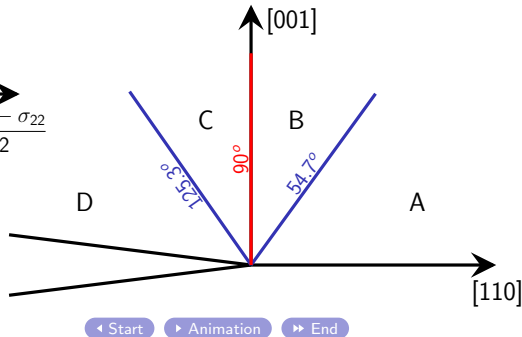
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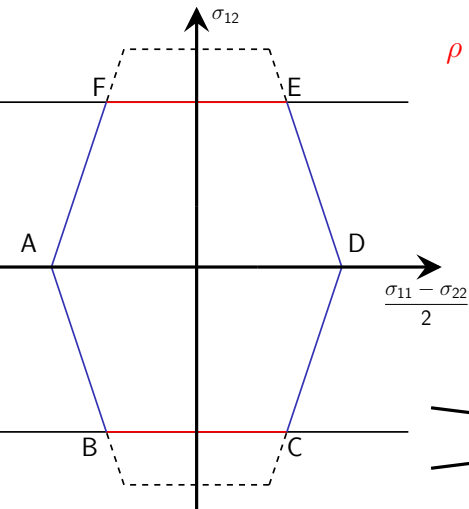
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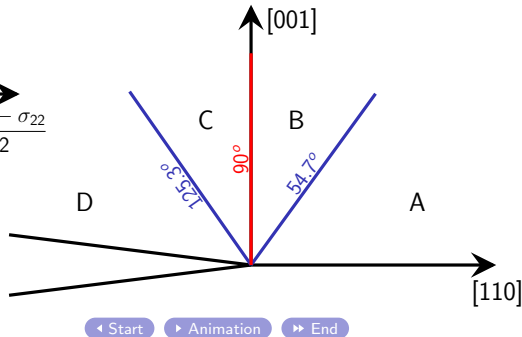
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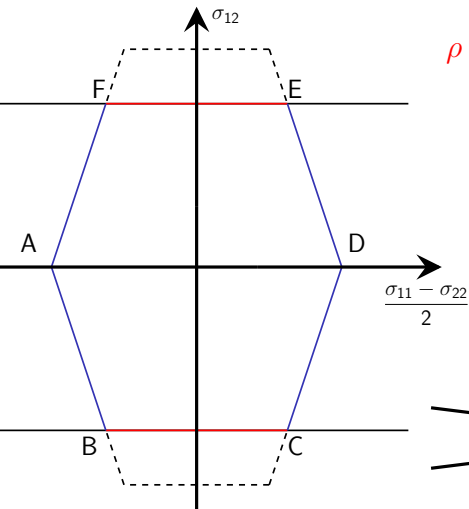
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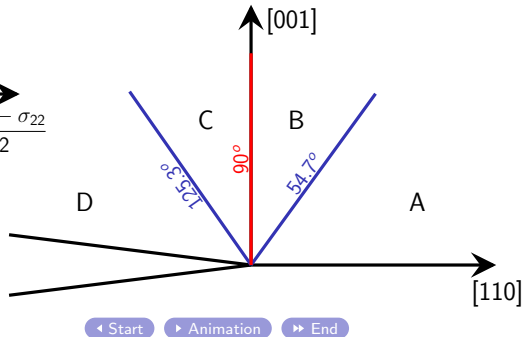
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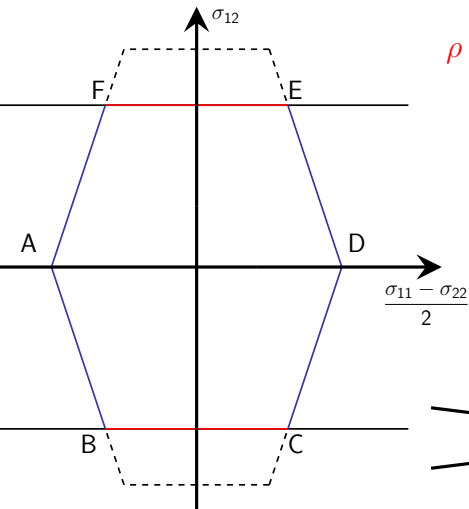
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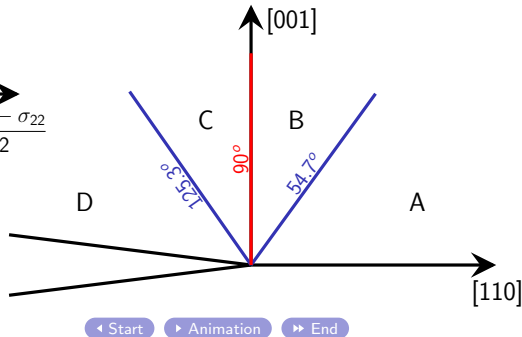
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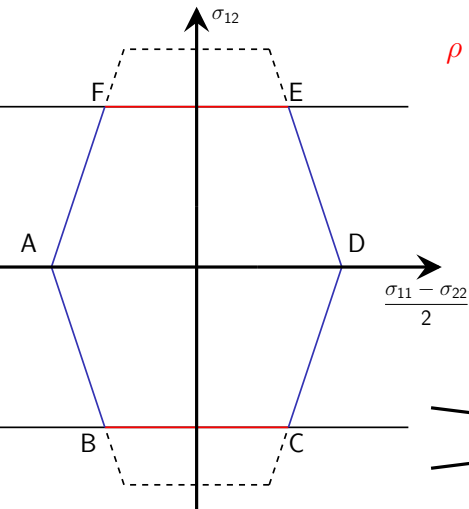
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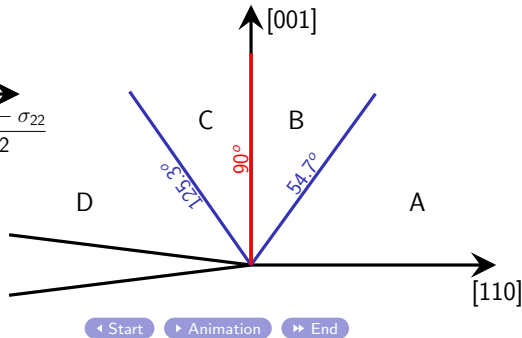
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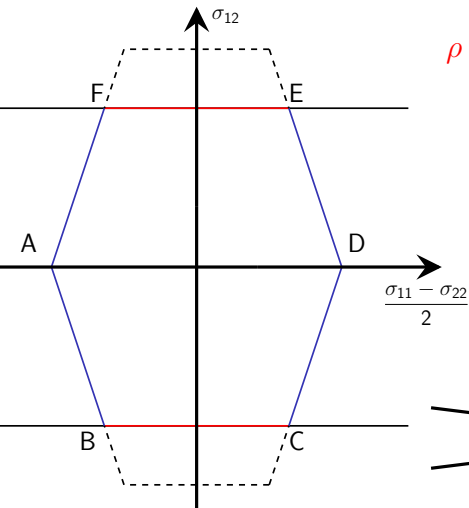
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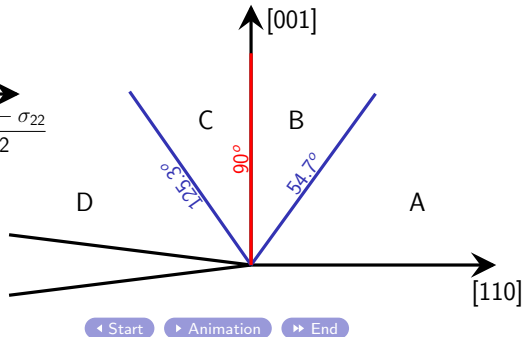
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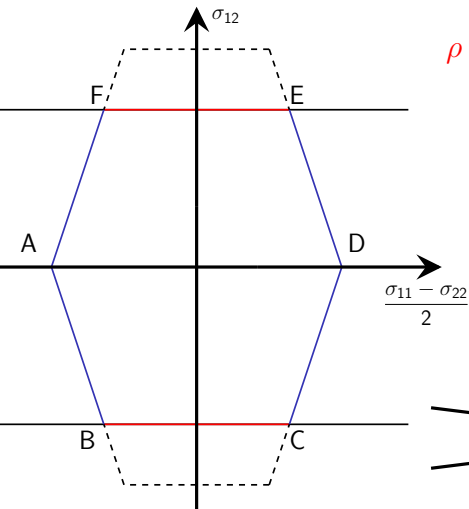
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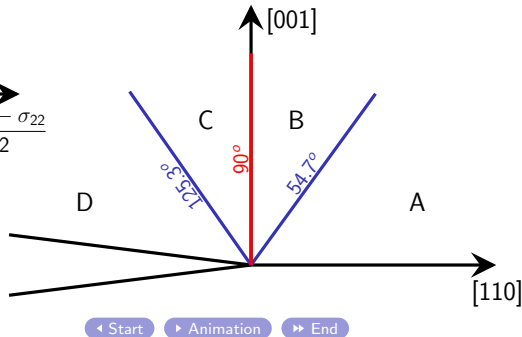
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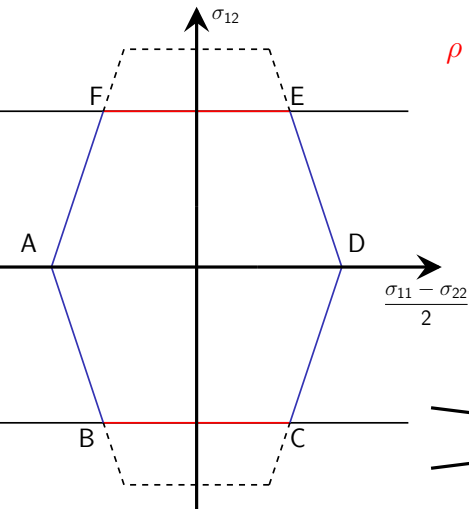
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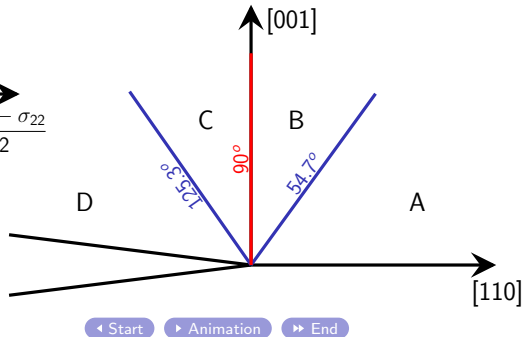
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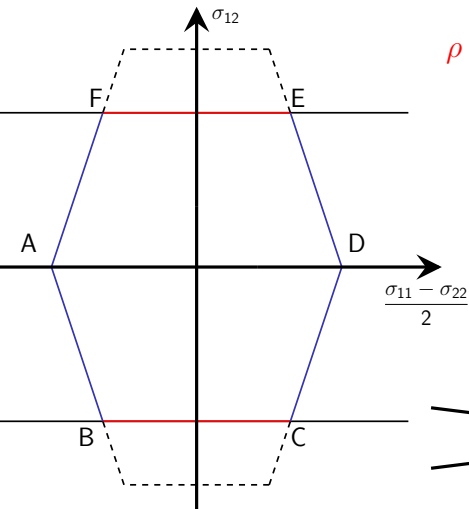
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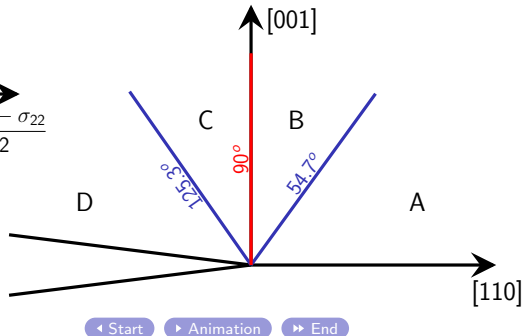
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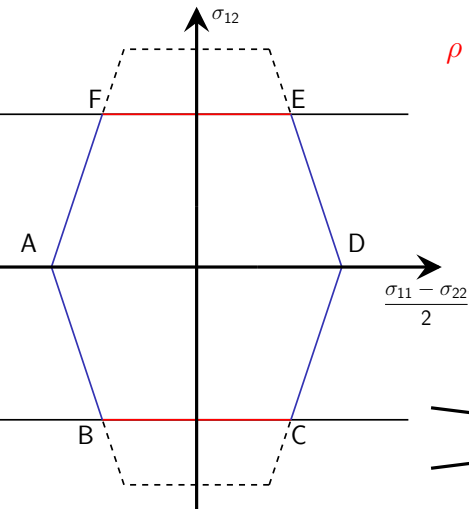
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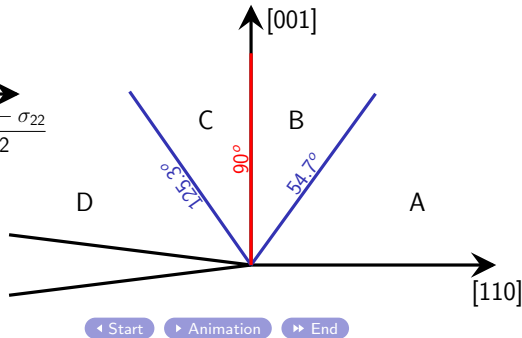
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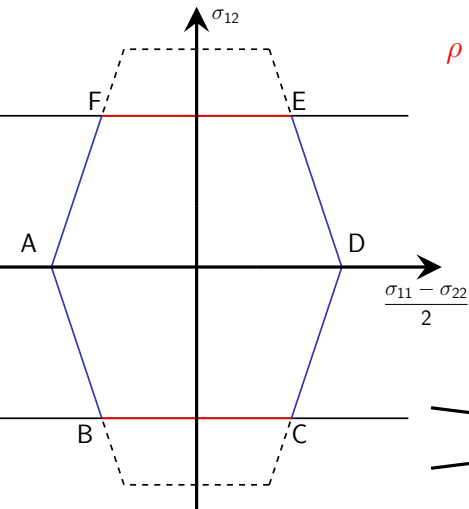
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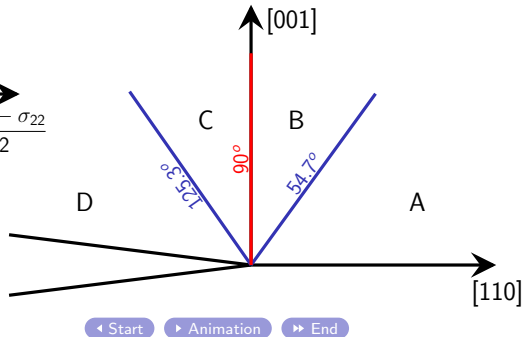
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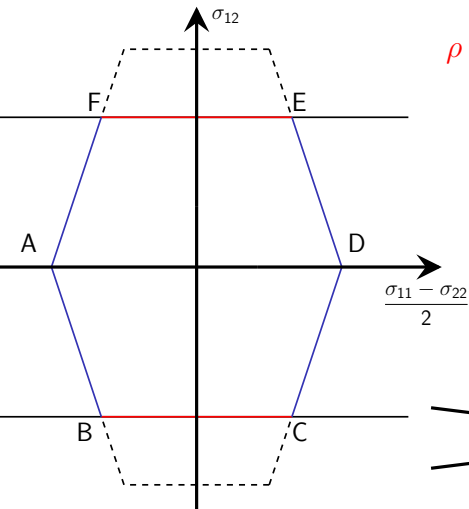
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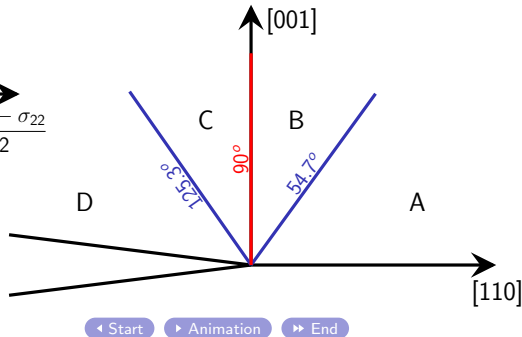
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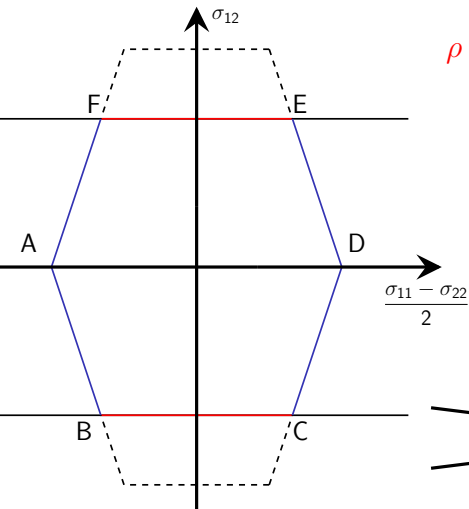
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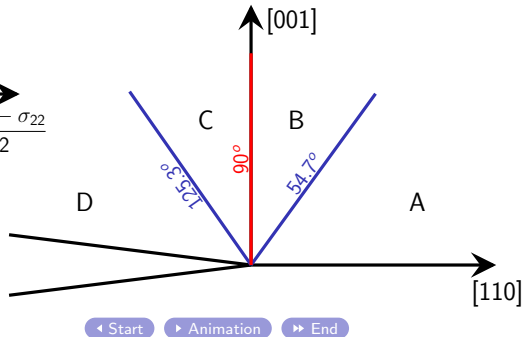
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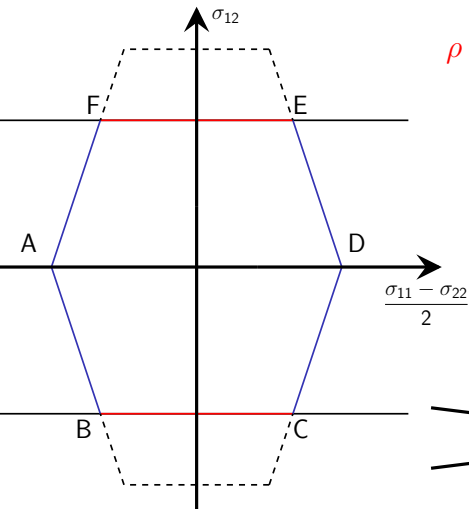
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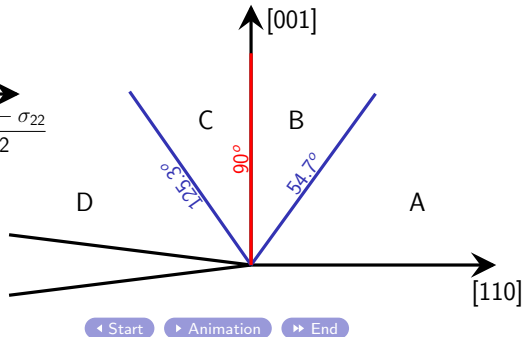
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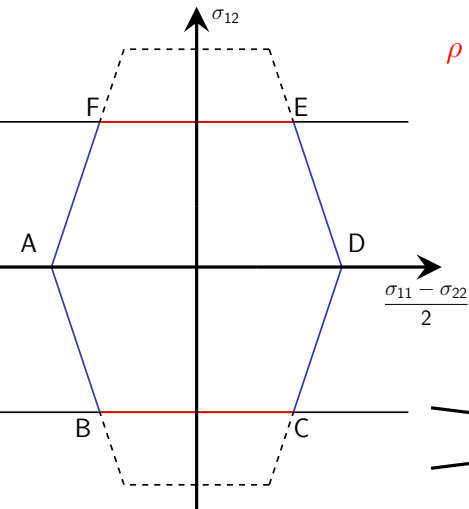
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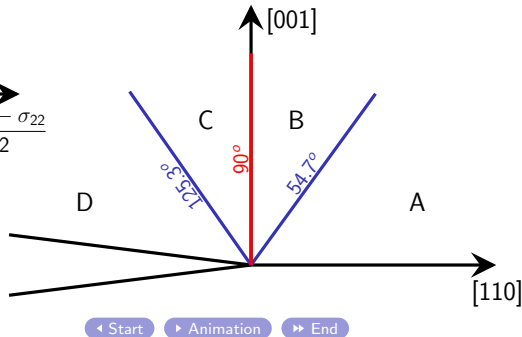
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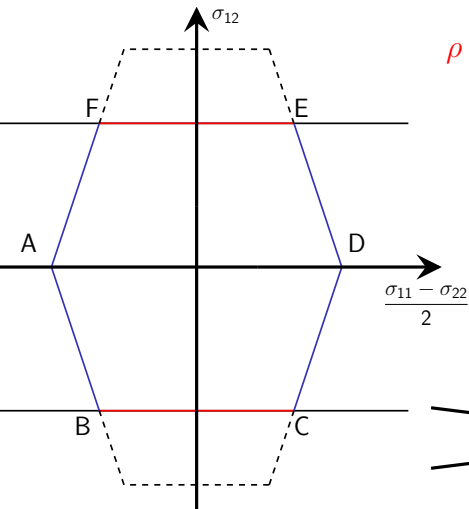
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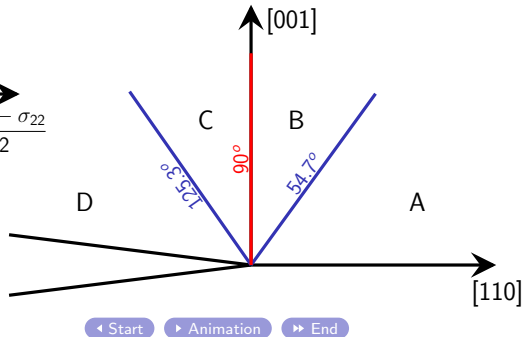
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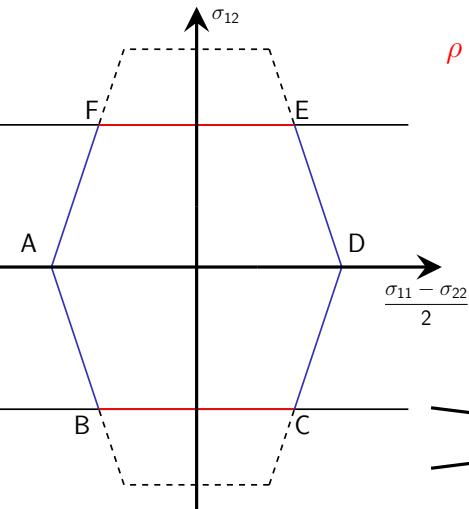
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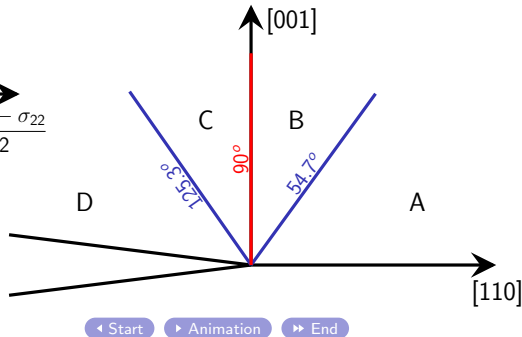
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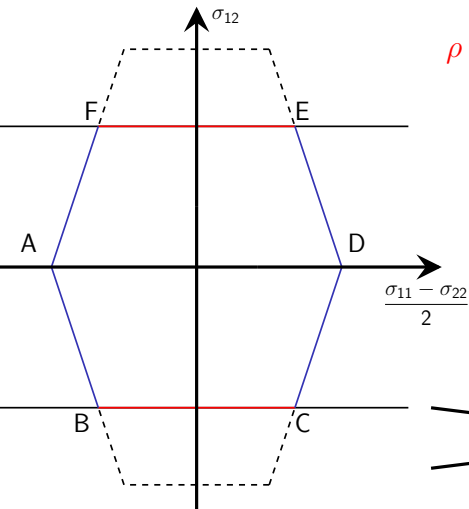
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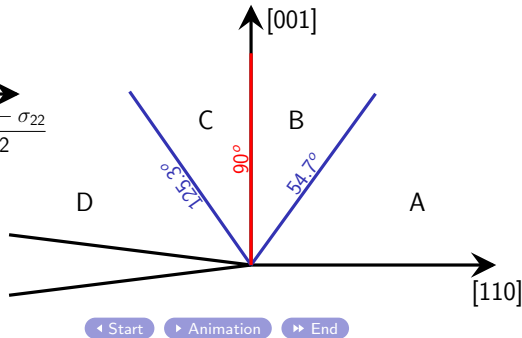
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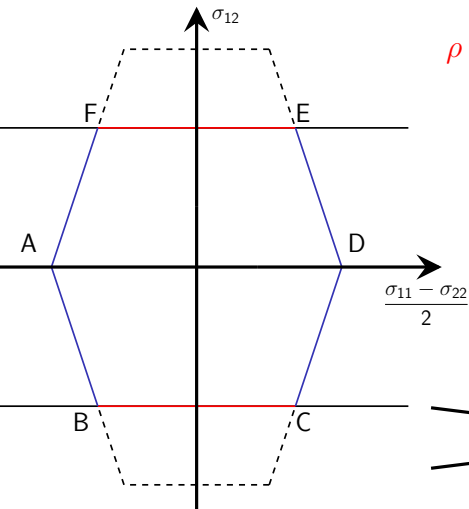
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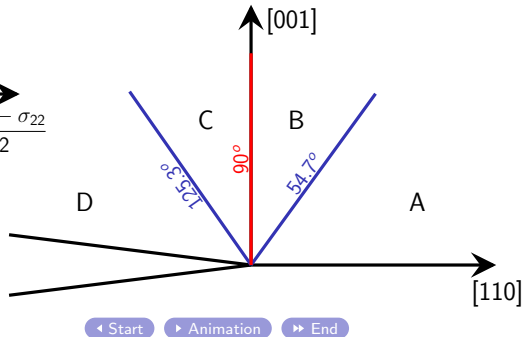
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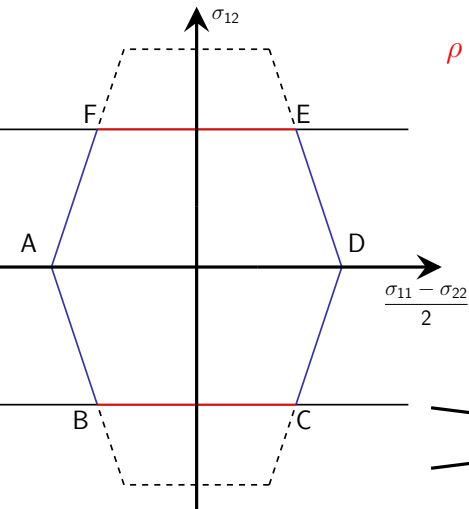
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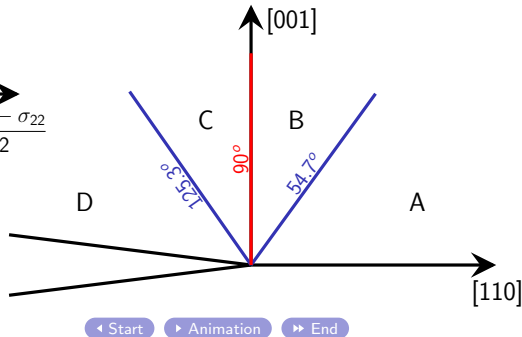
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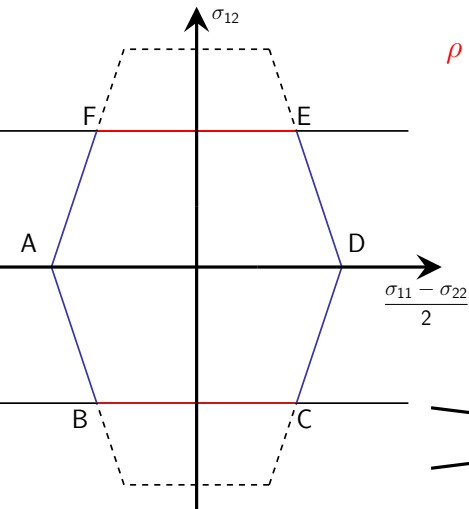
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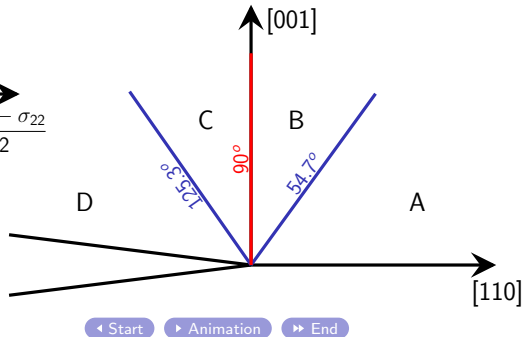
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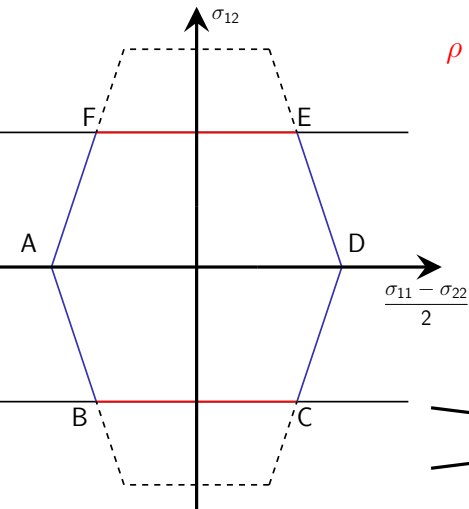
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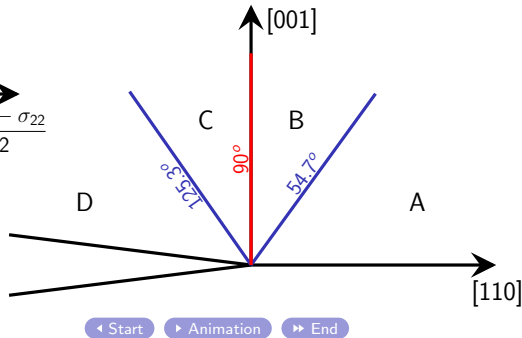
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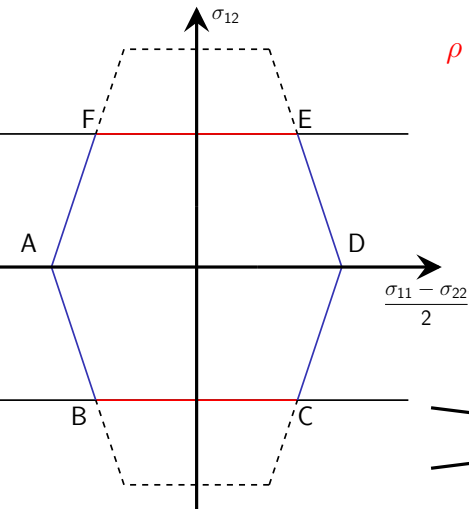
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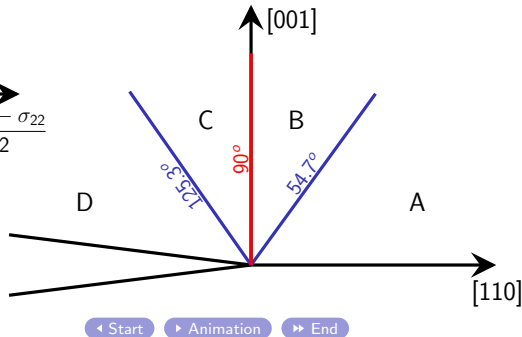
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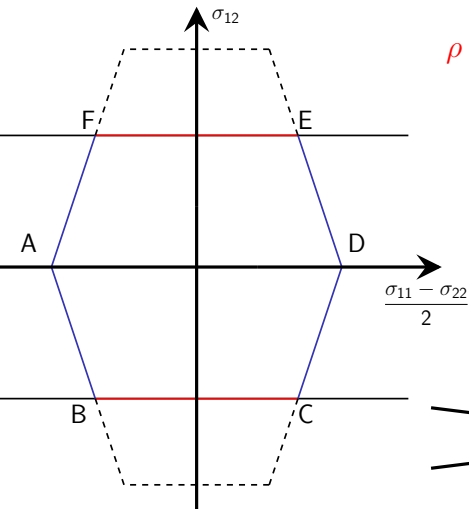
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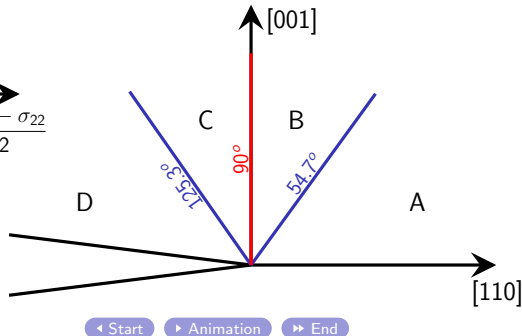
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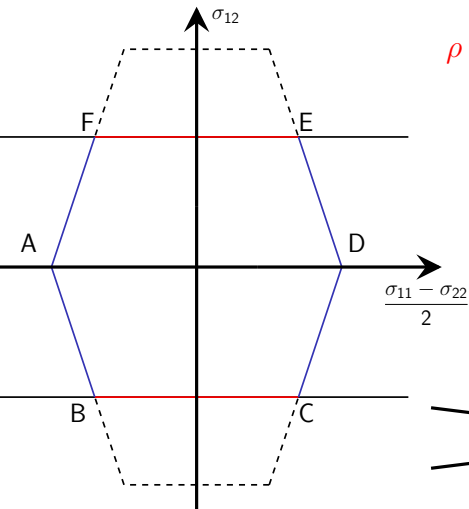
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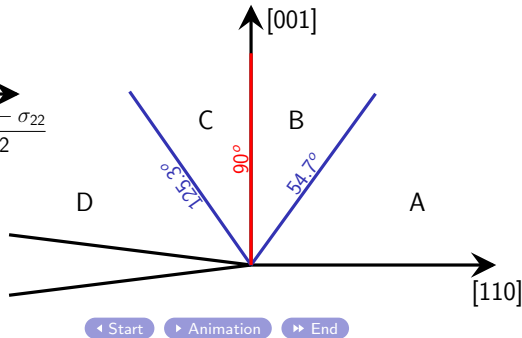
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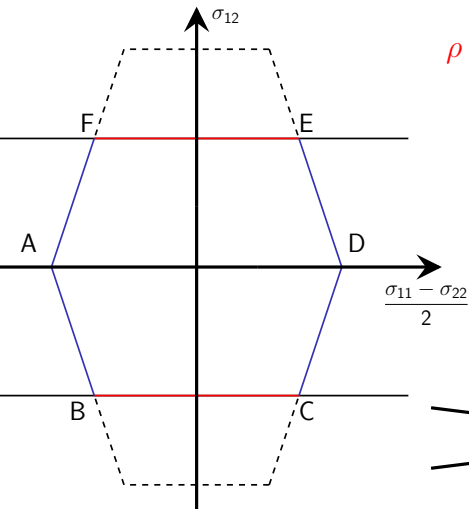
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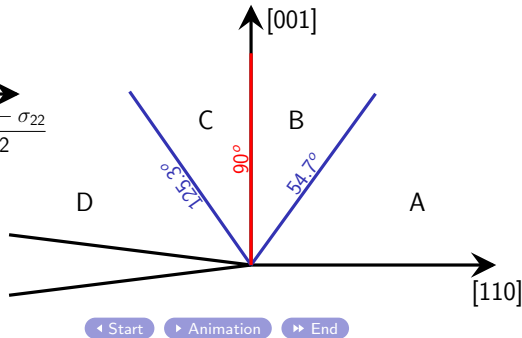
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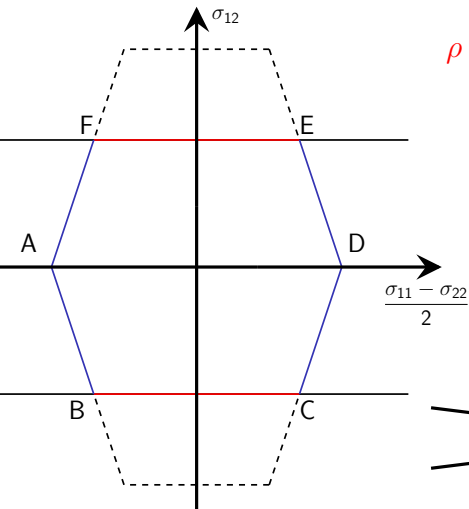
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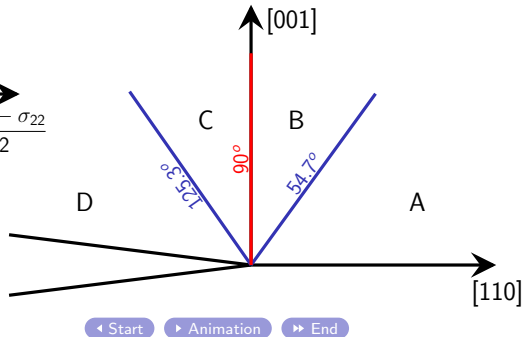
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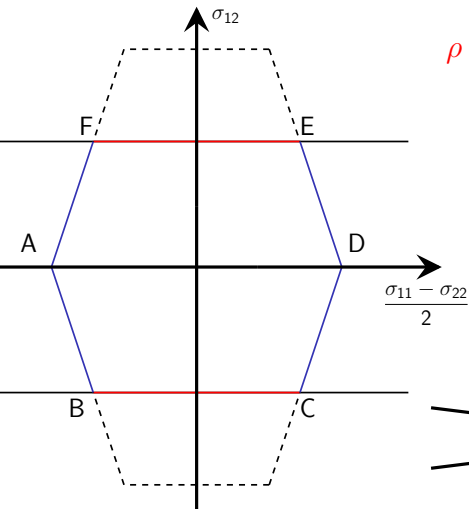
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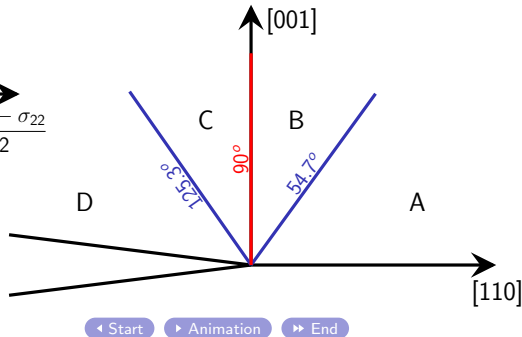
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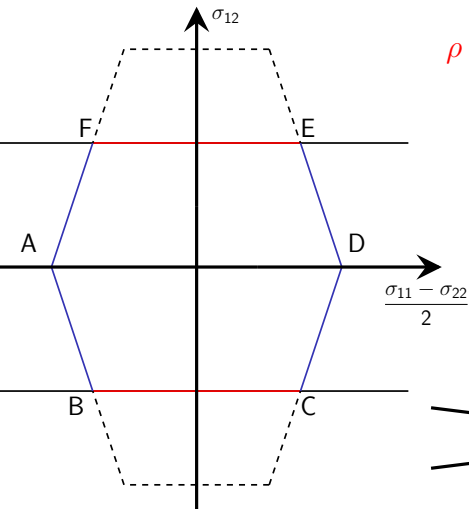
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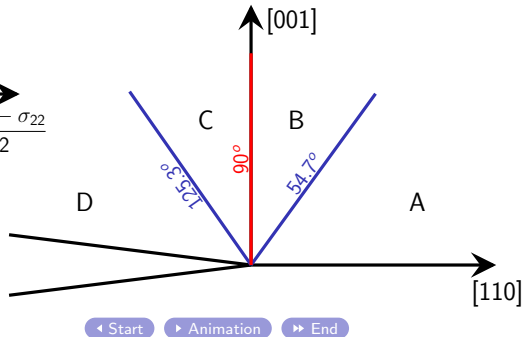
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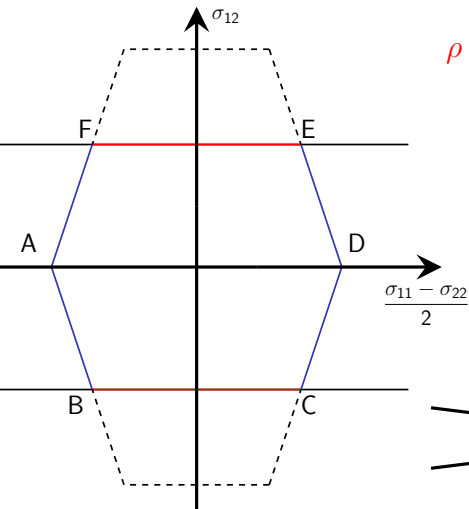
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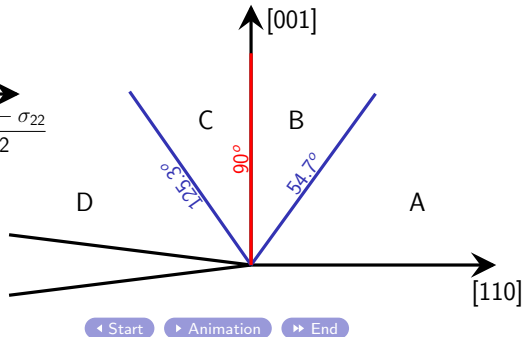
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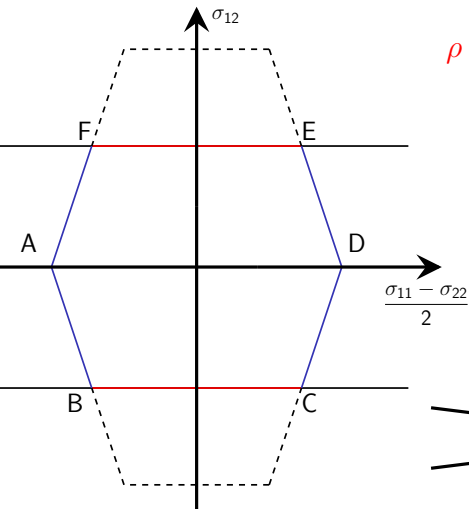
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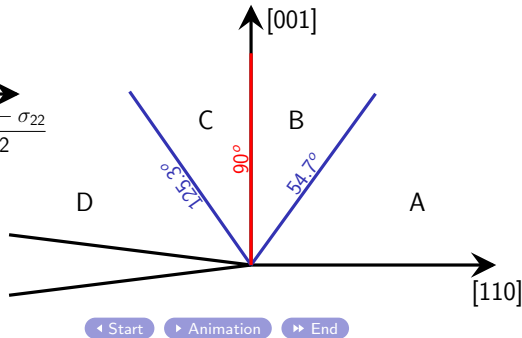
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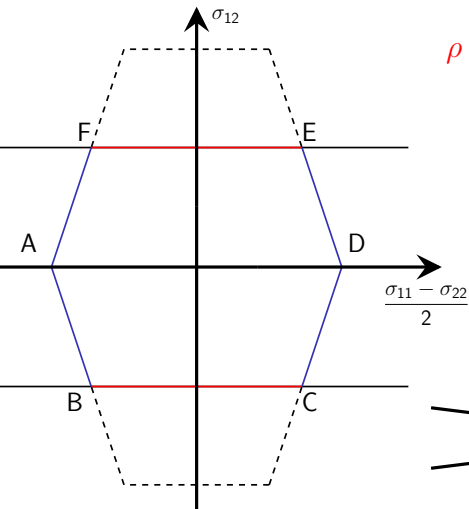
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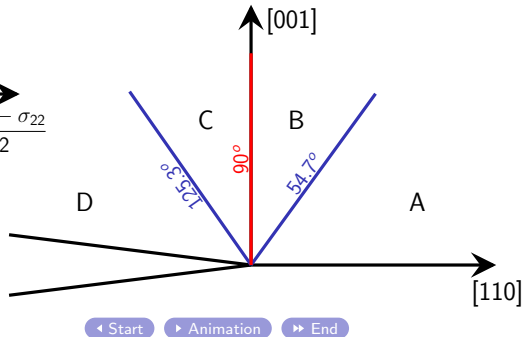
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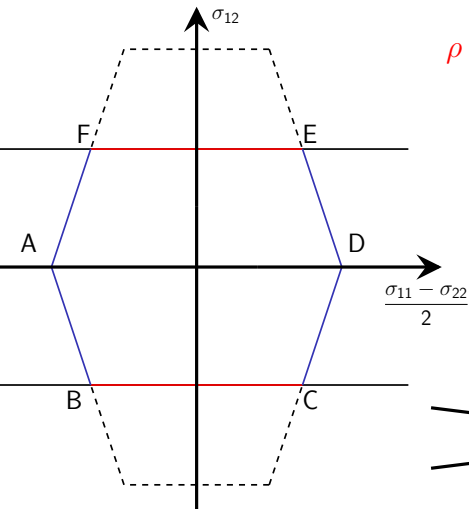
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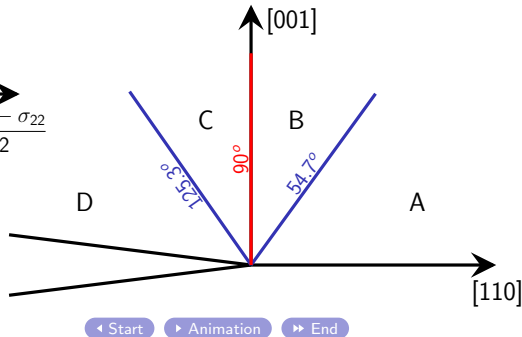
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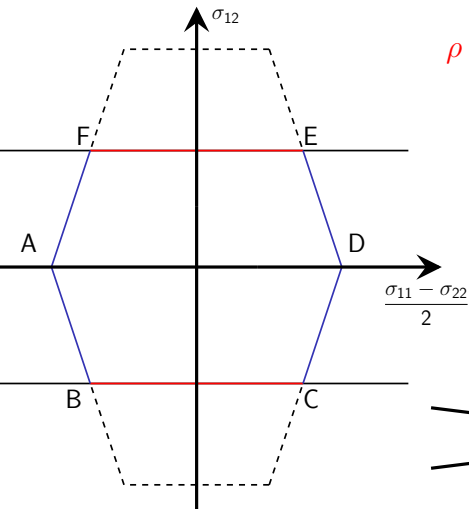
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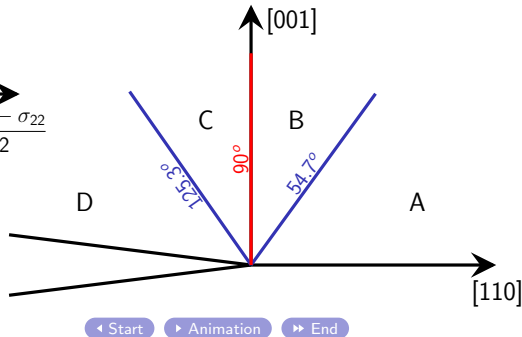
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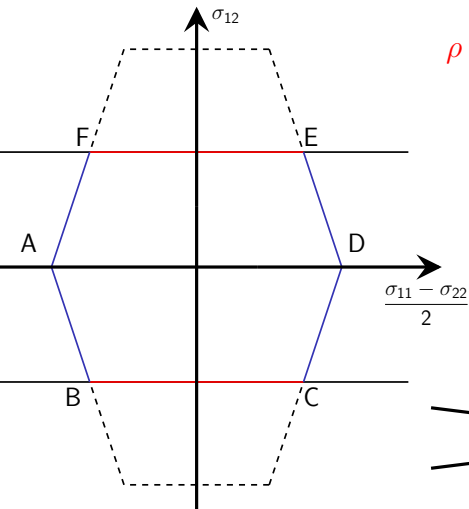
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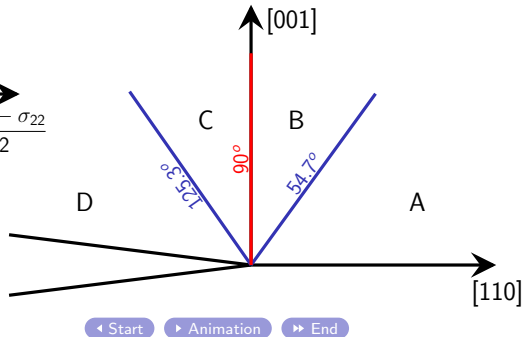
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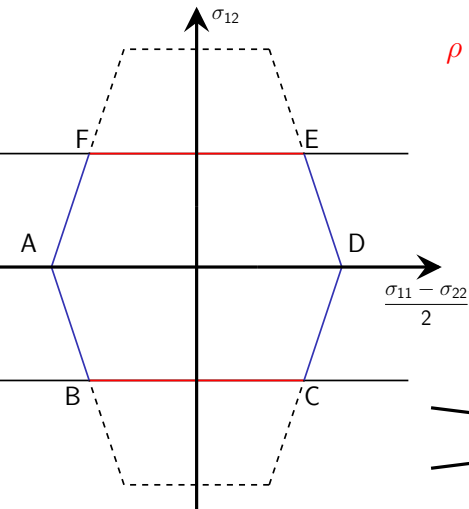
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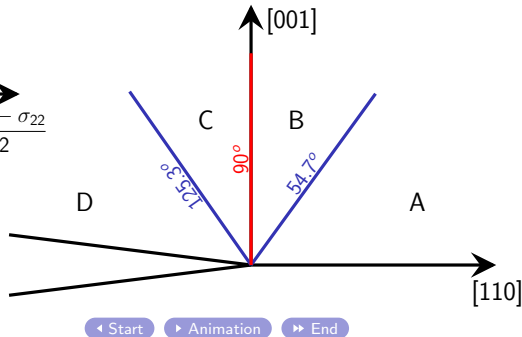
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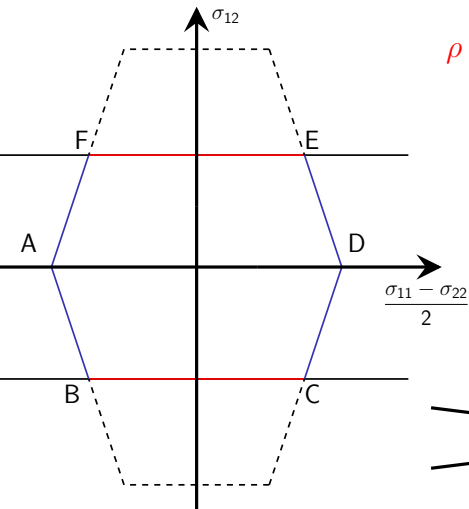
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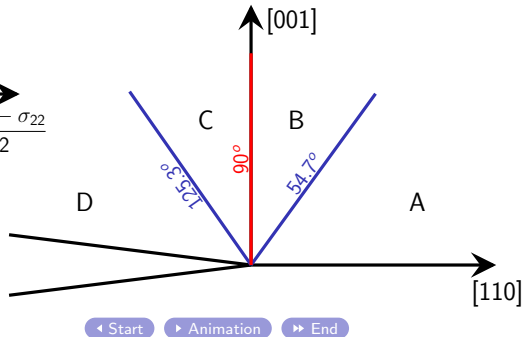
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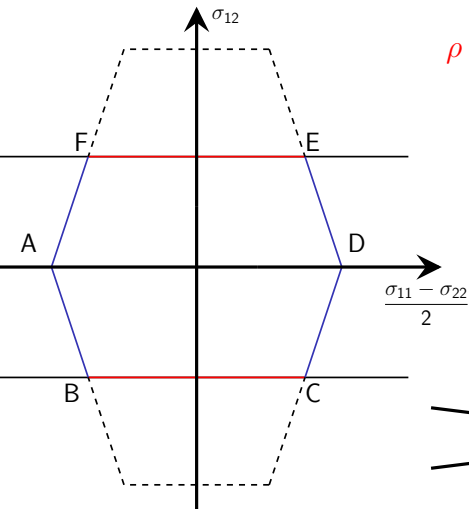
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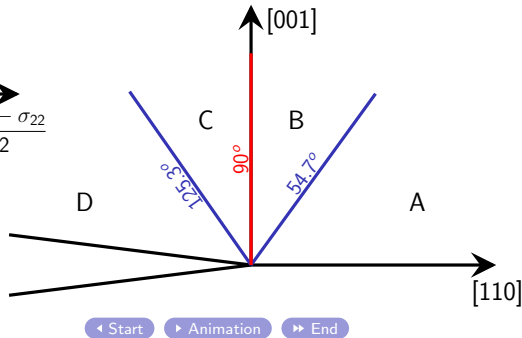
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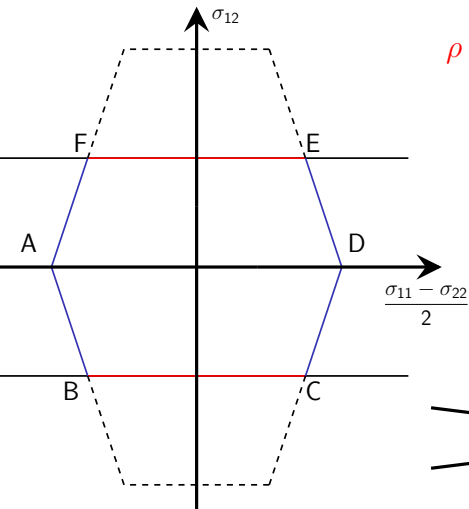
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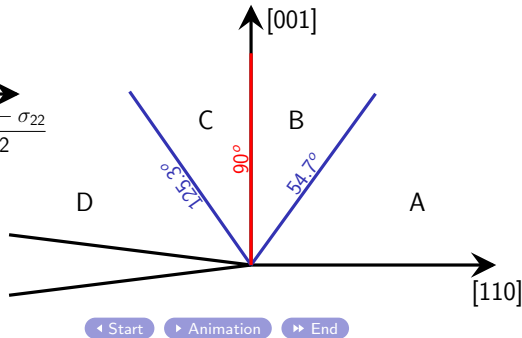
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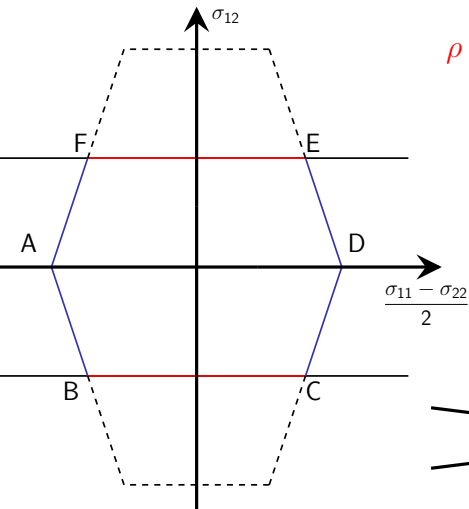
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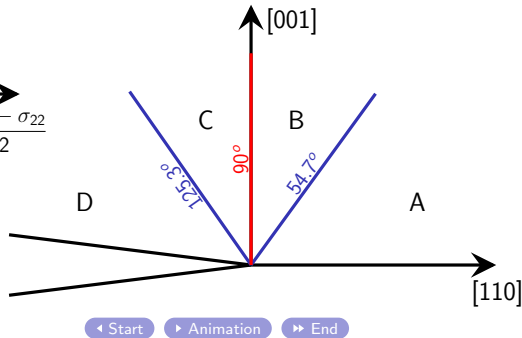
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Extension to cube slip systems



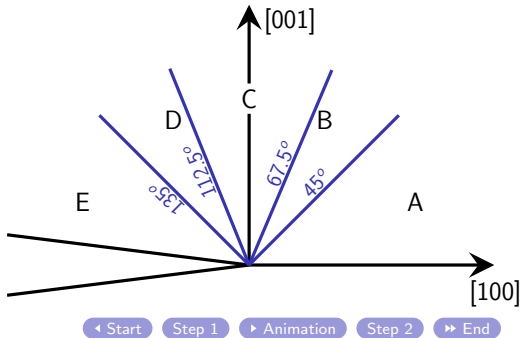
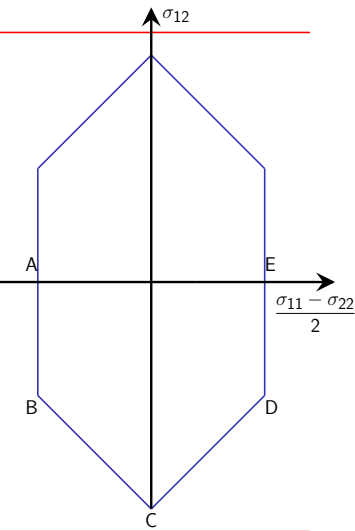
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



Application to a new orientation

Orientation $C \rightarrow (001)[100]$

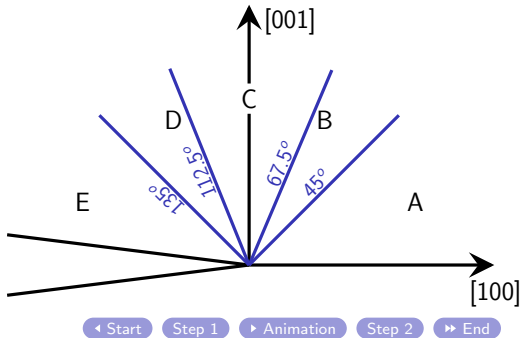
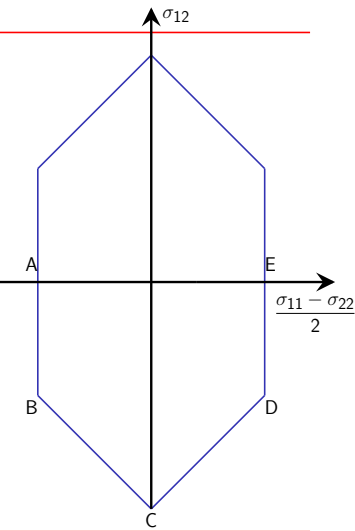
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

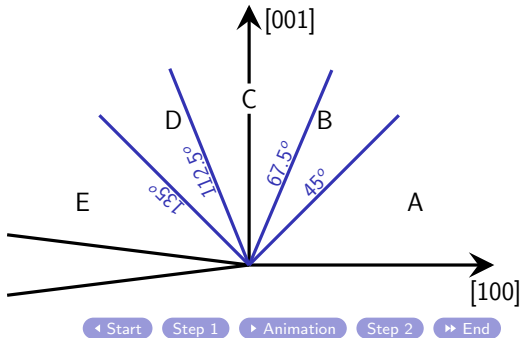
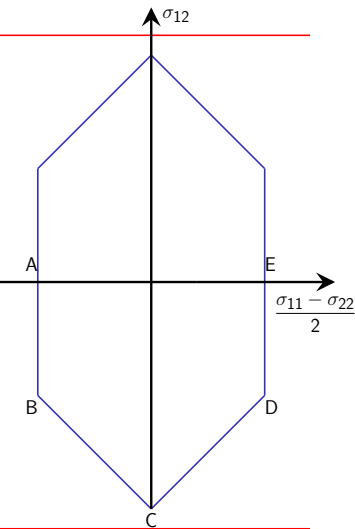
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

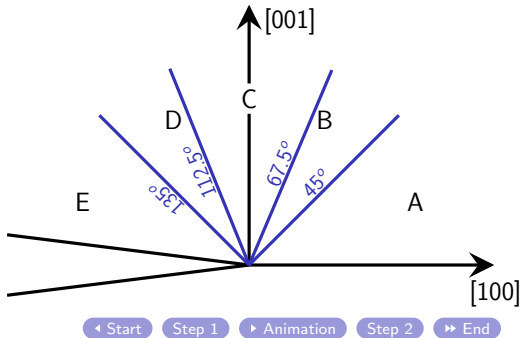
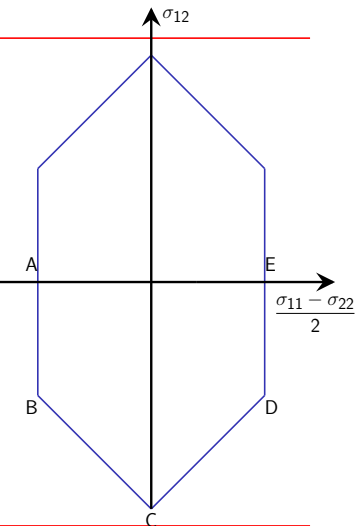
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

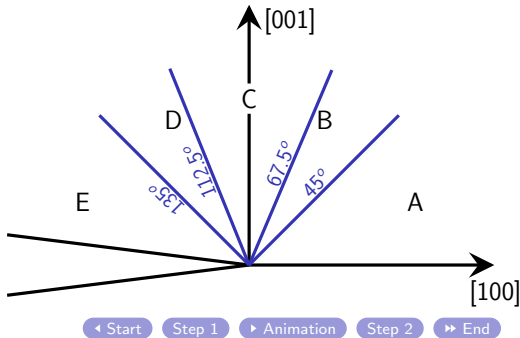
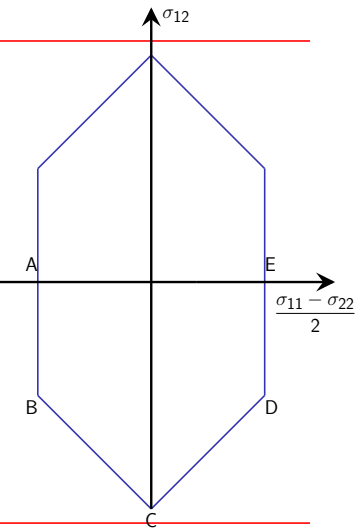
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

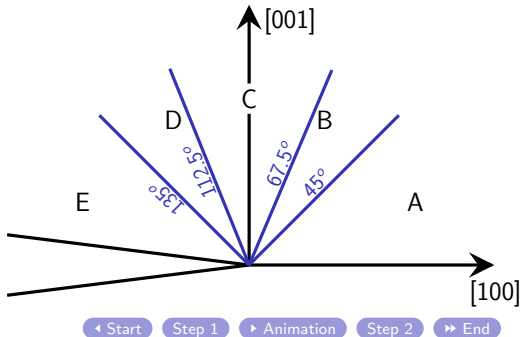
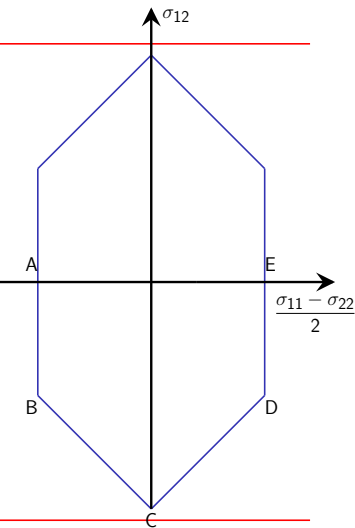
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



Application to a new orientation

Orientation $C \rightarrow (001)[100]$

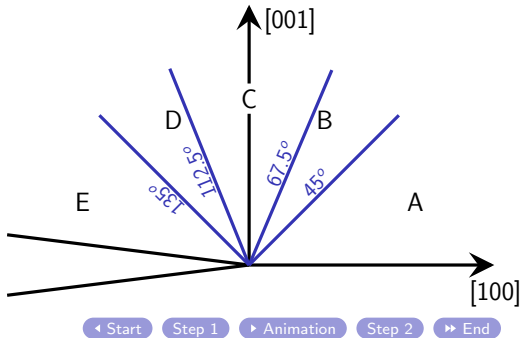
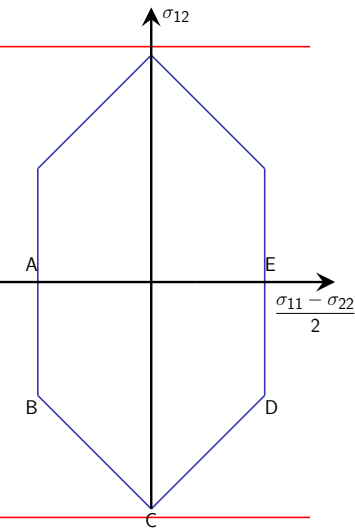
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



Application to a new orientation

Orientation $C \rightarrow (001)[100]$

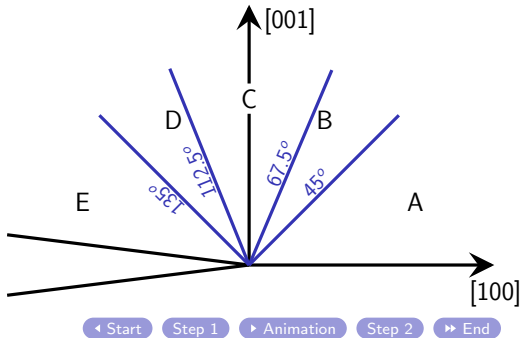
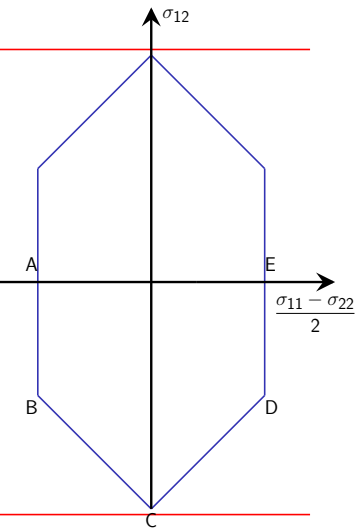
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



Application to a new orientation

Orientation $C \rightarrow (001)[100]$

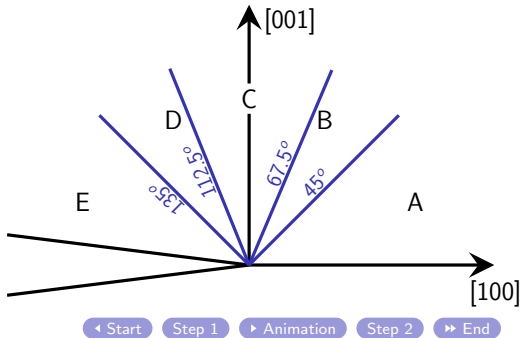
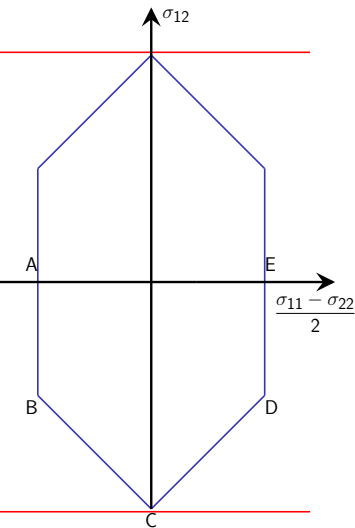
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



Application to a new orientation

Orientation $C \rightarrow (001)[100]$

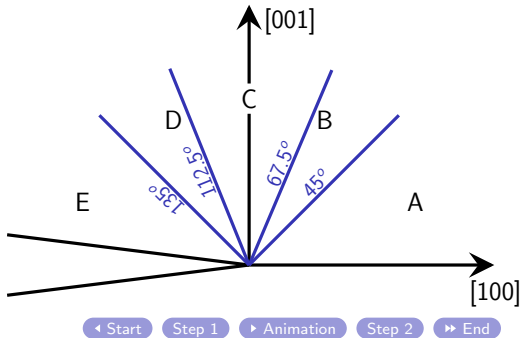
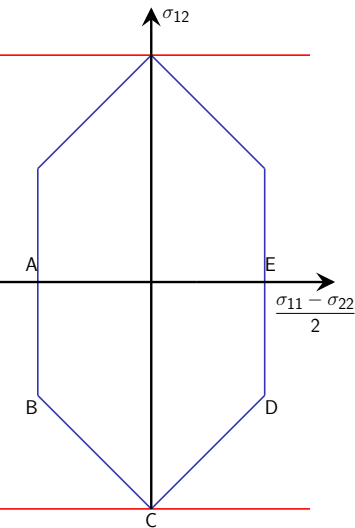
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



Application to a new orientation

Orientation $C \rightarrow (001)[100]$

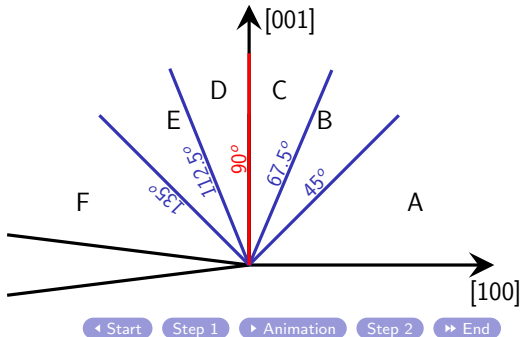
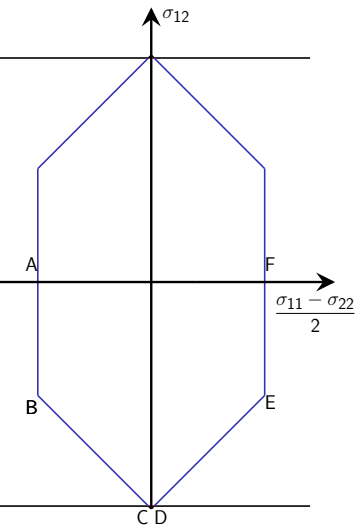
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \geq \sqrt{3}$$



Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

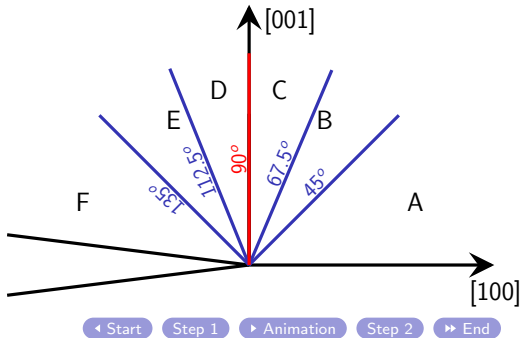
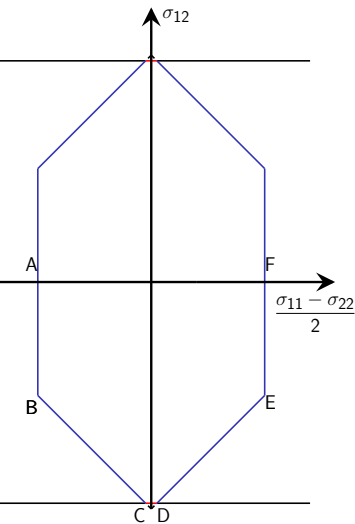
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

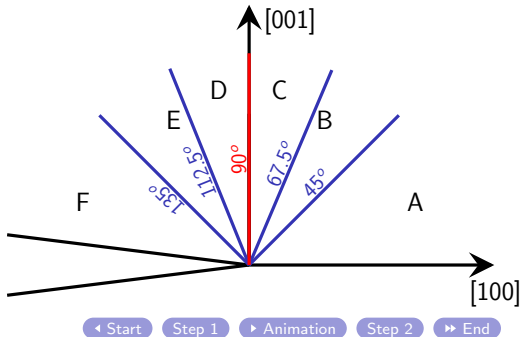
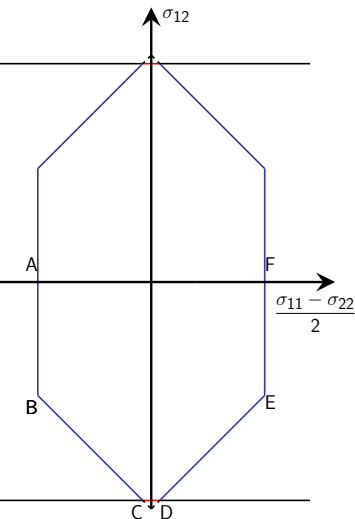
$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

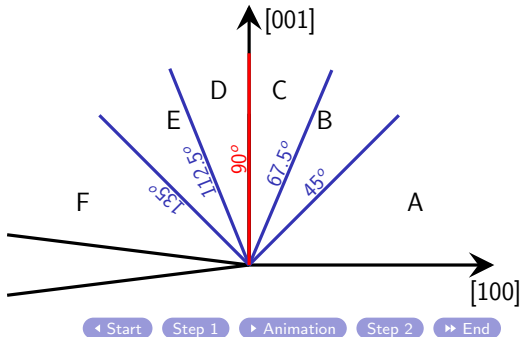
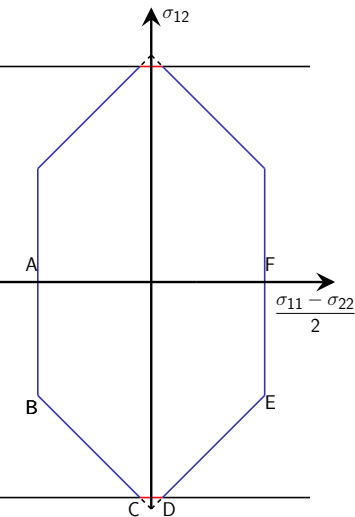
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

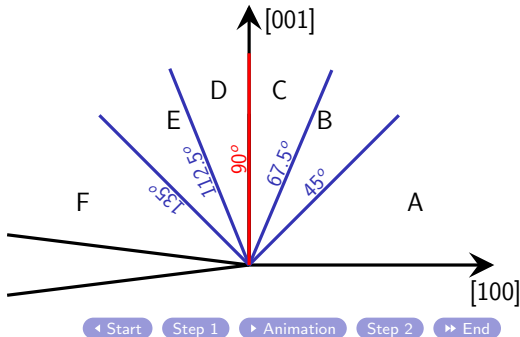
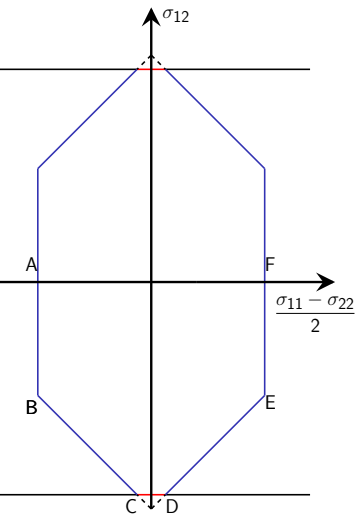
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

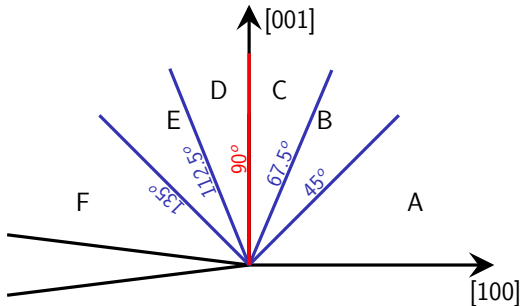
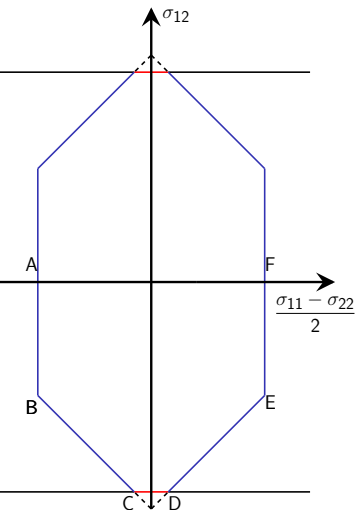
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

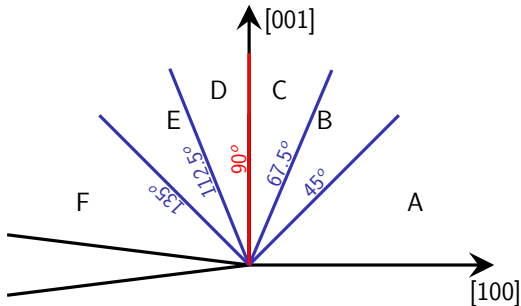
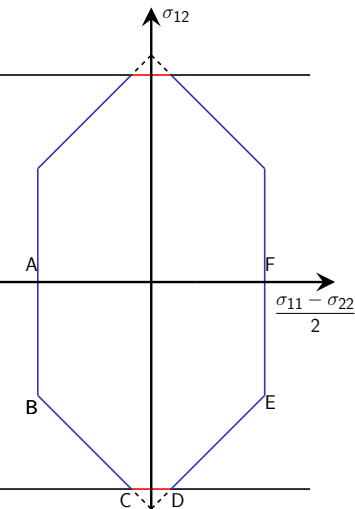
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

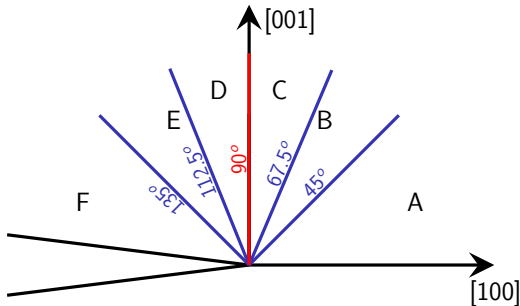
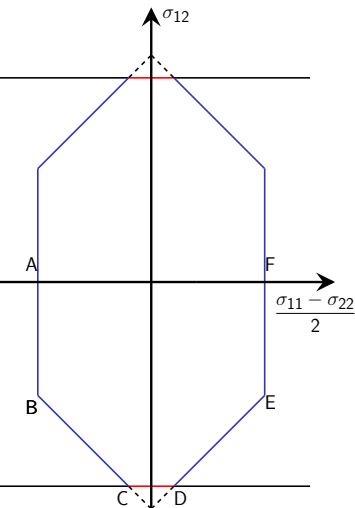
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

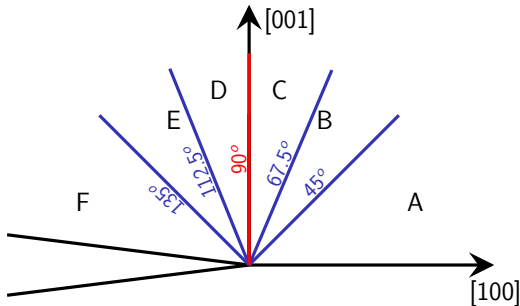
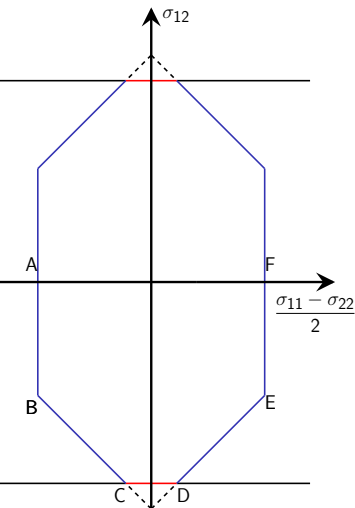
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

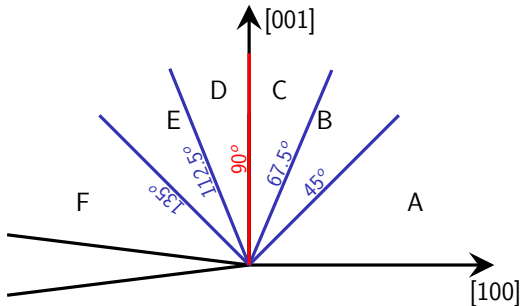
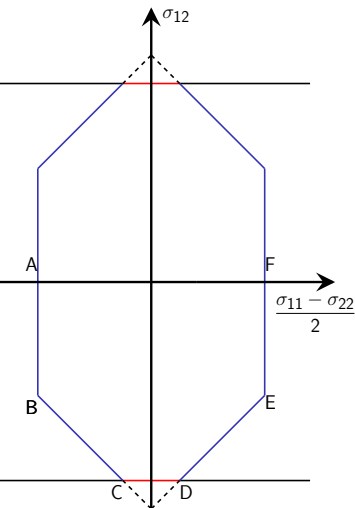
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

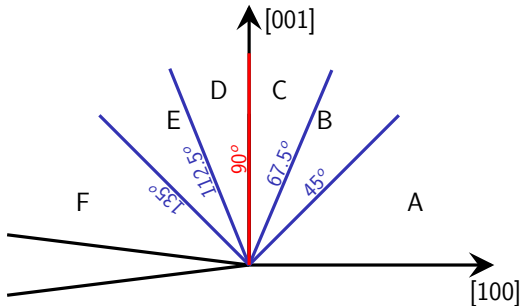
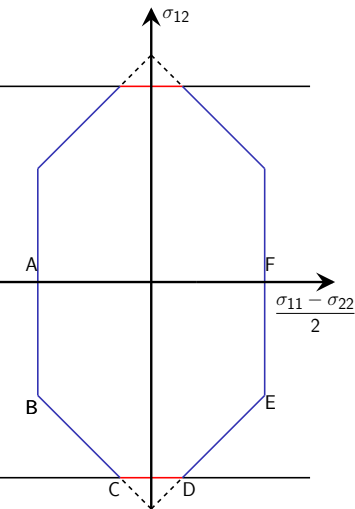
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

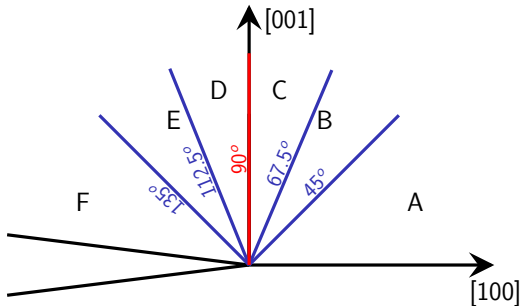
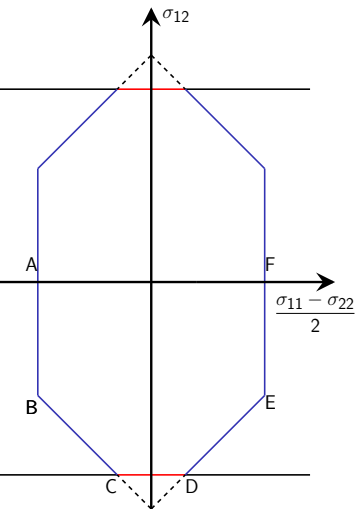
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

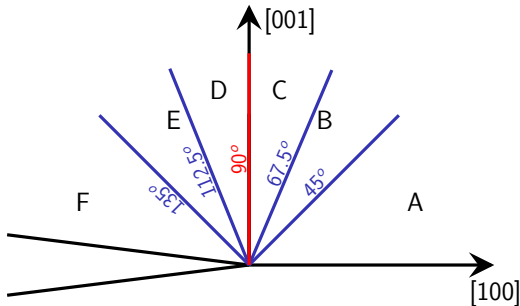
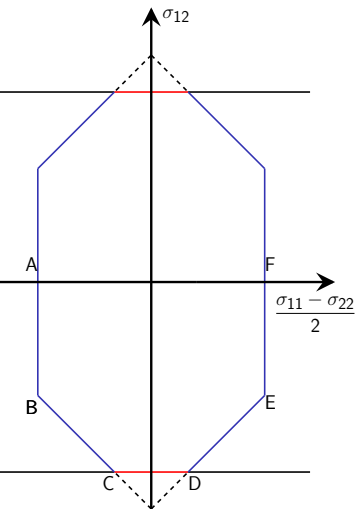
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

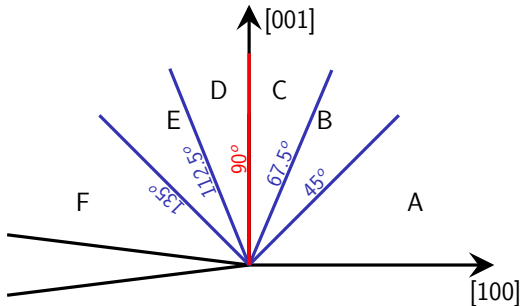
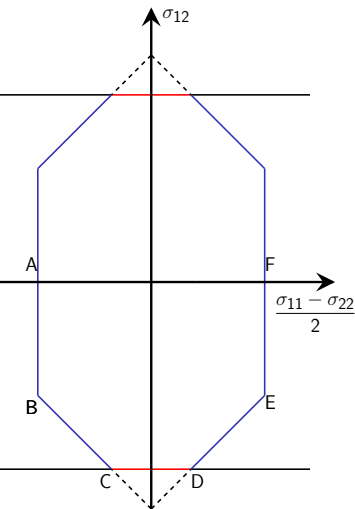
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

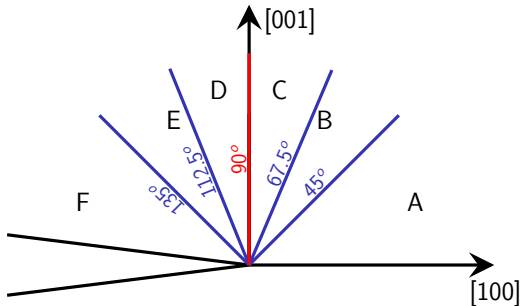
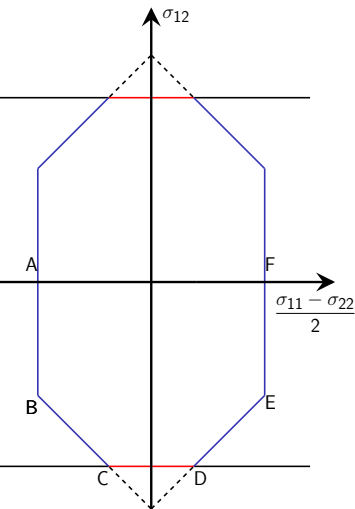
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

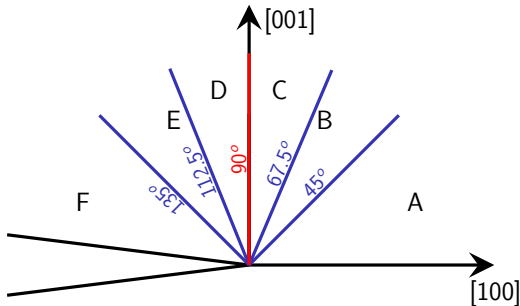
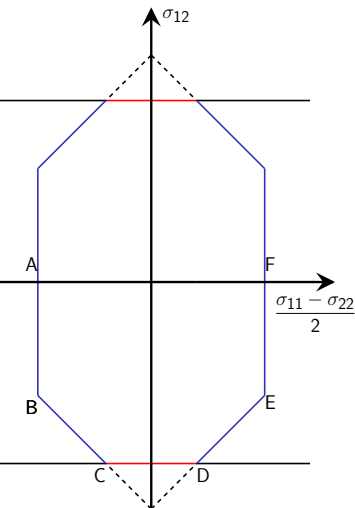
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

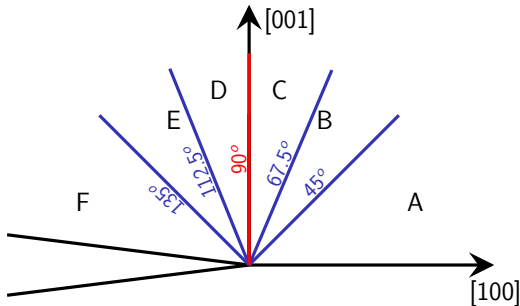
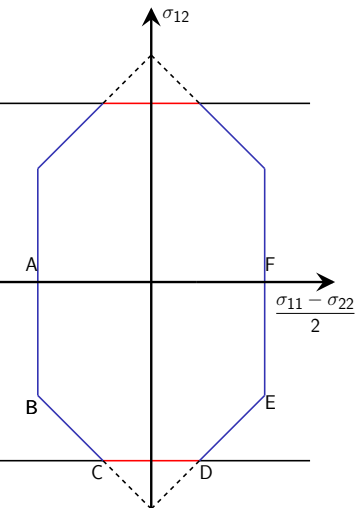
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$

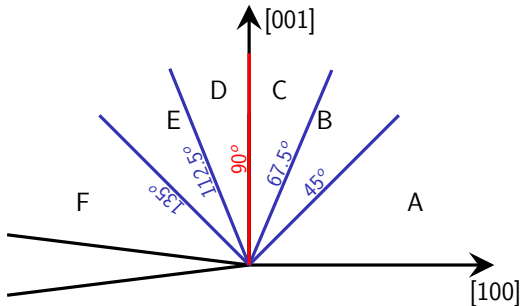
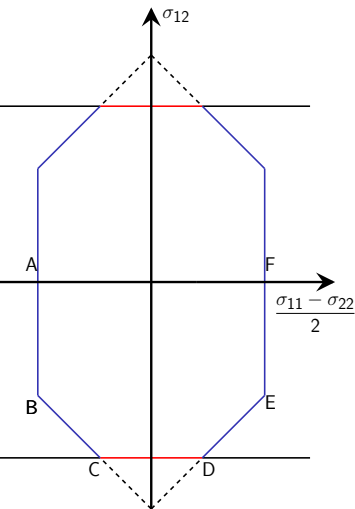


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

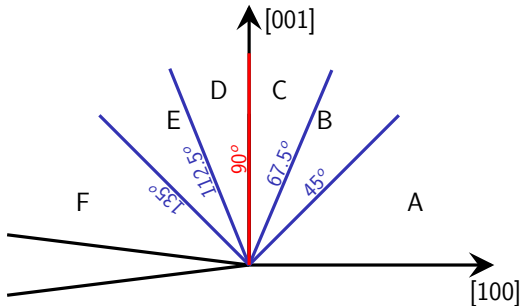
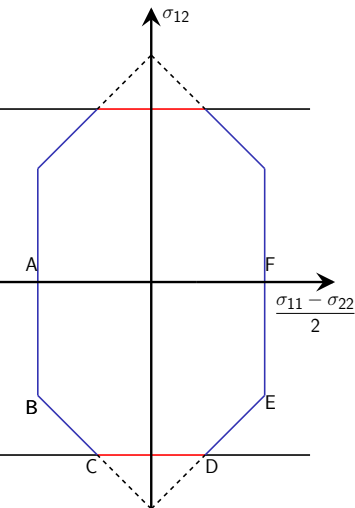
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

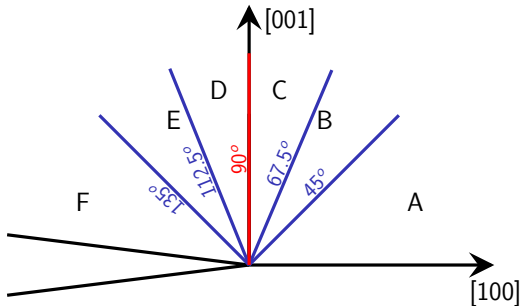
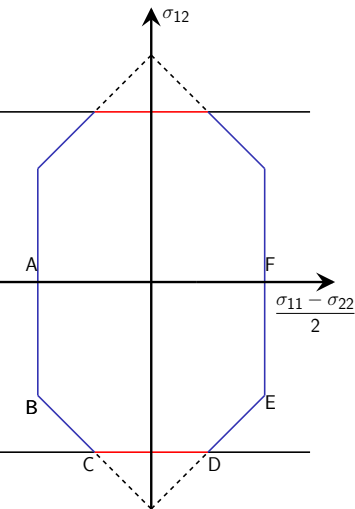
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

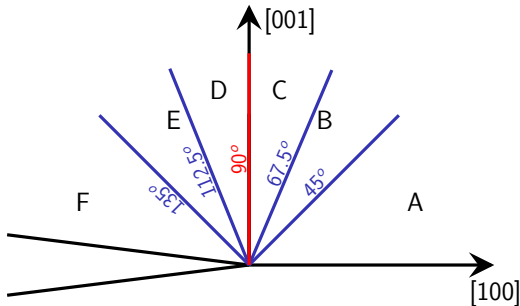
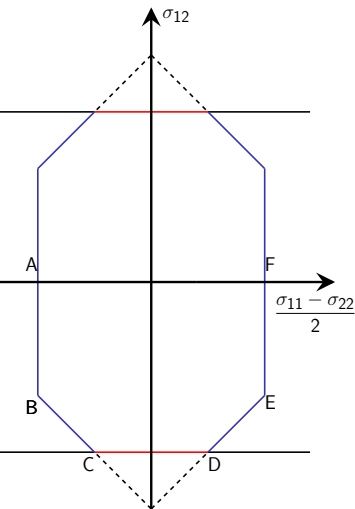
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

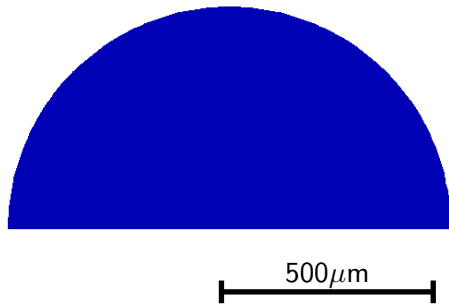
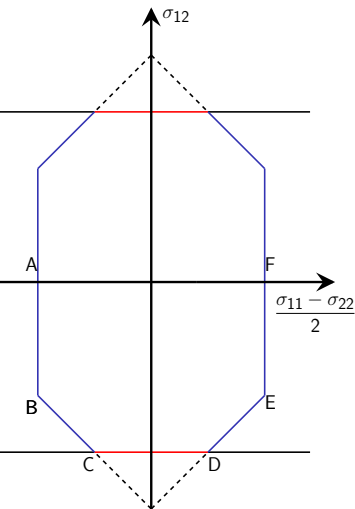
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

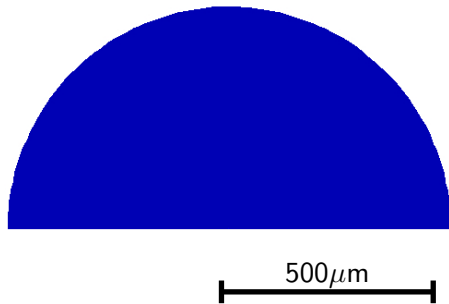
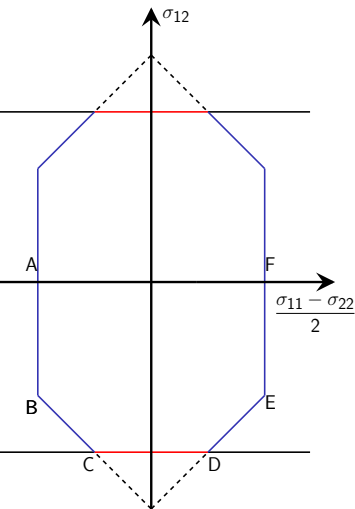
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

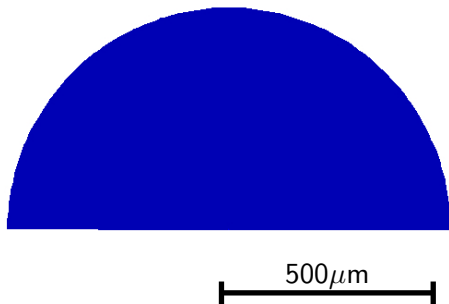
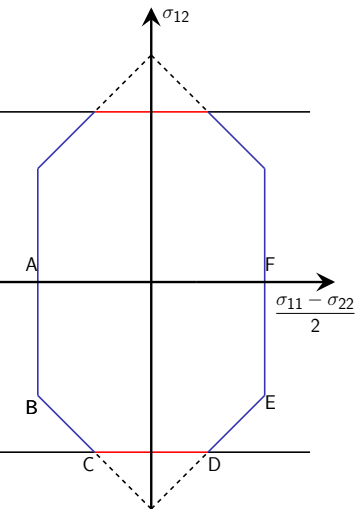
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

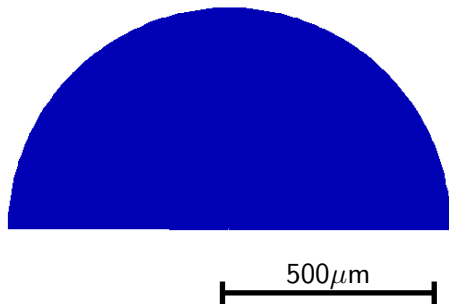
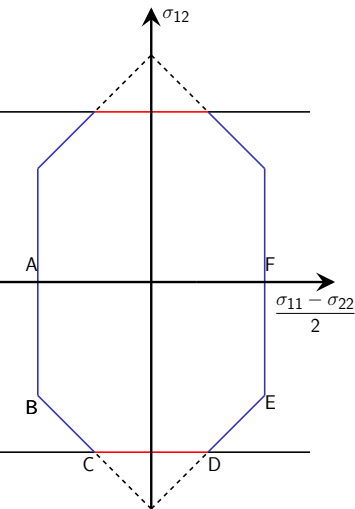
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

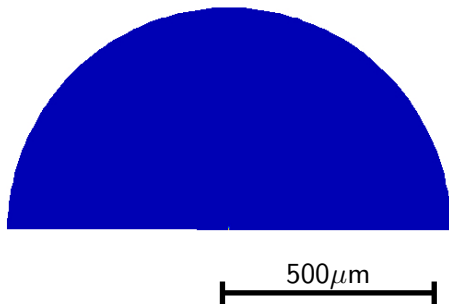
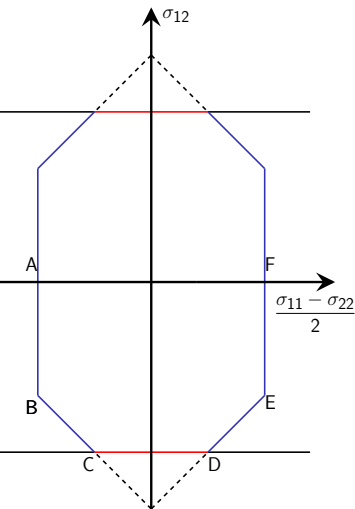
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

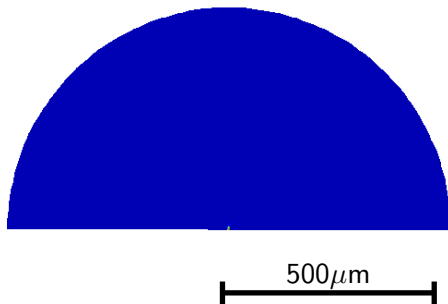
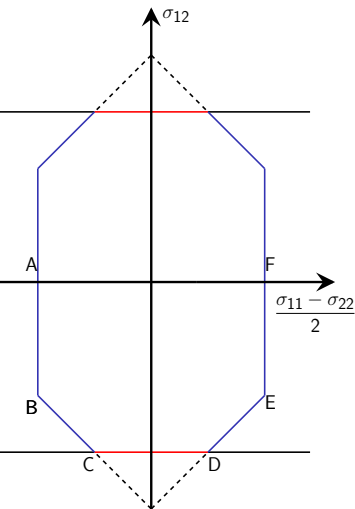
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

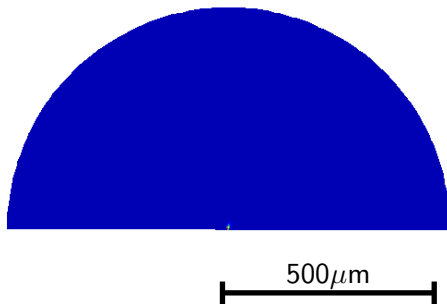
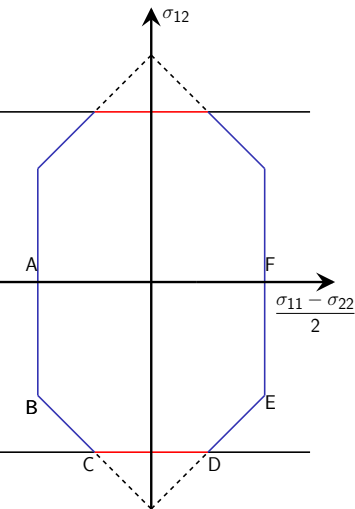
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

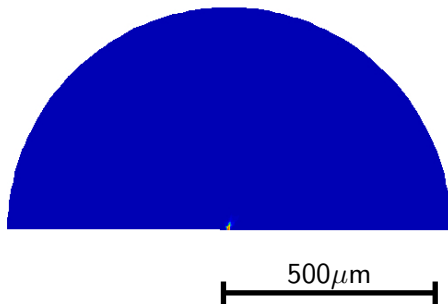
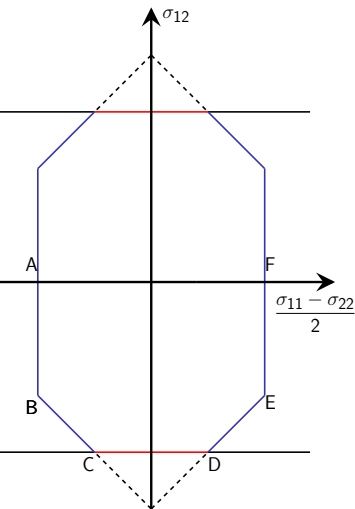
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

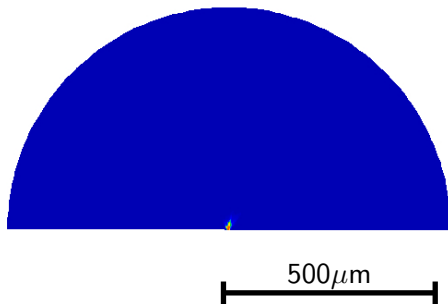
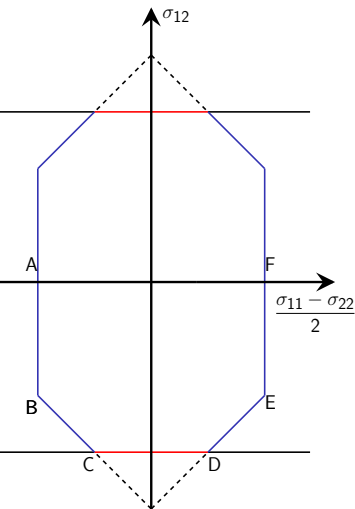
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

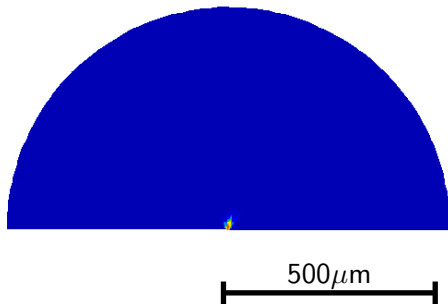
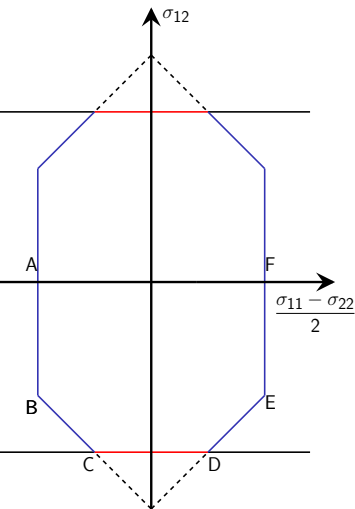
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

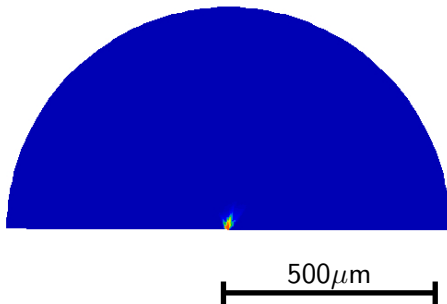
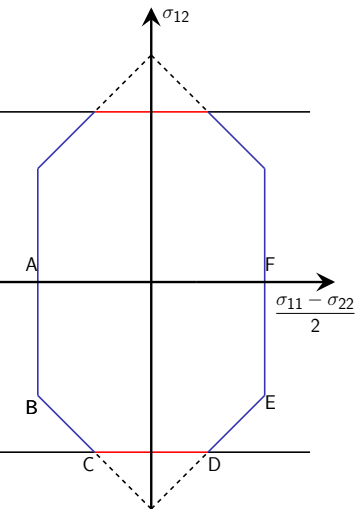
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

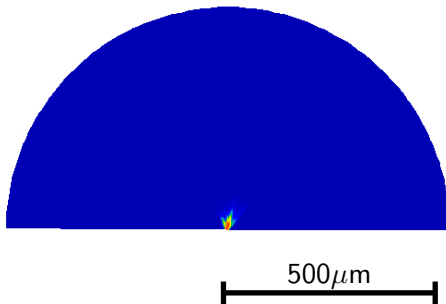
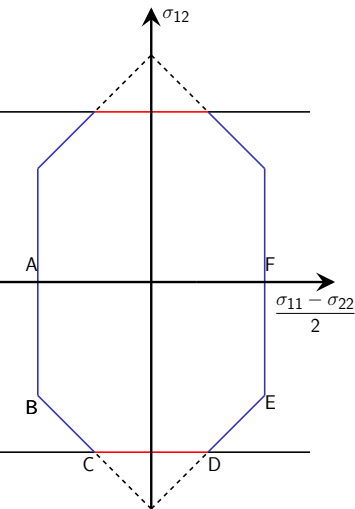
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

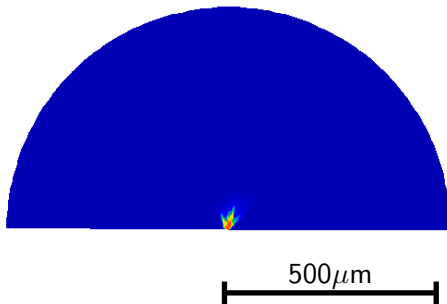
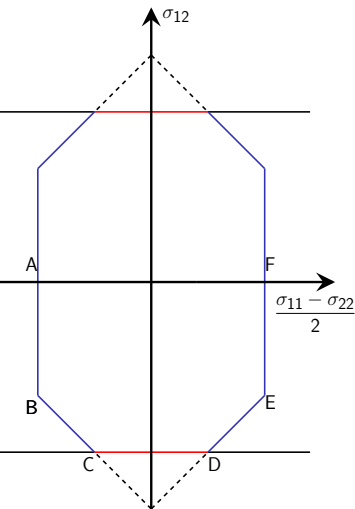
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

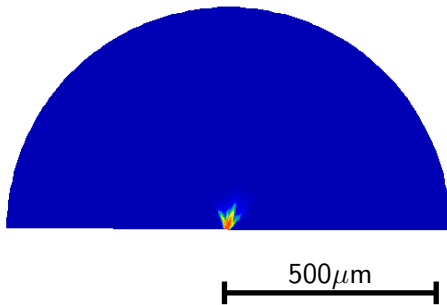
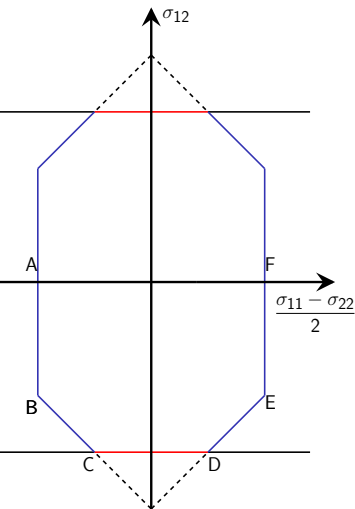
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

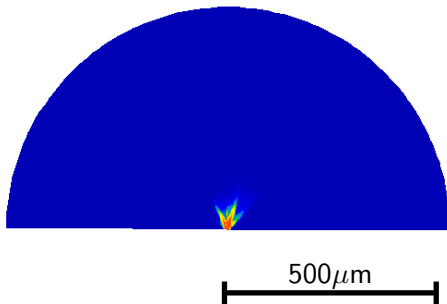
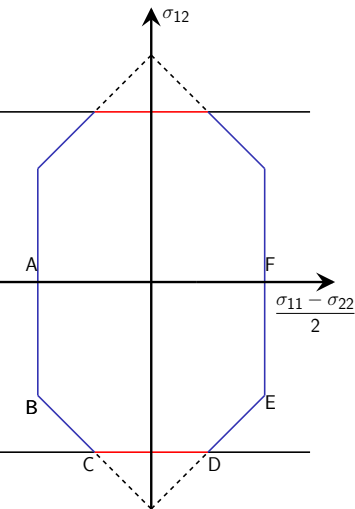
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

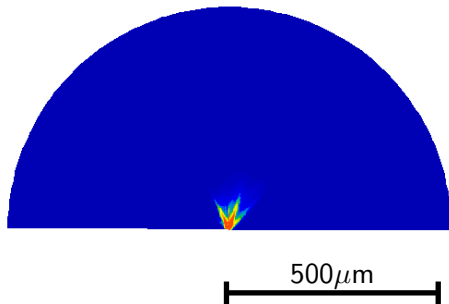
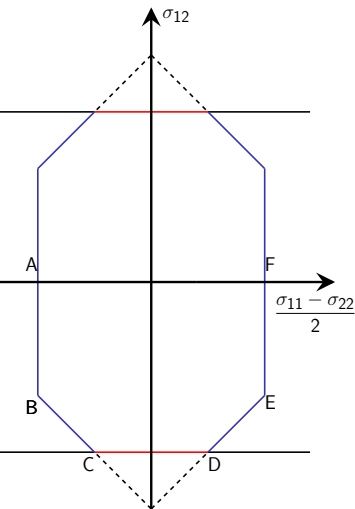
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

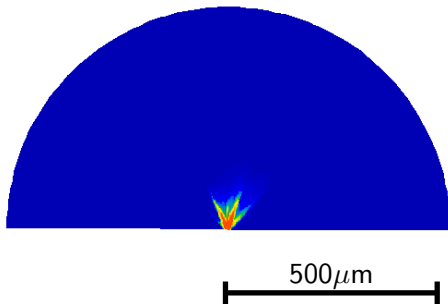
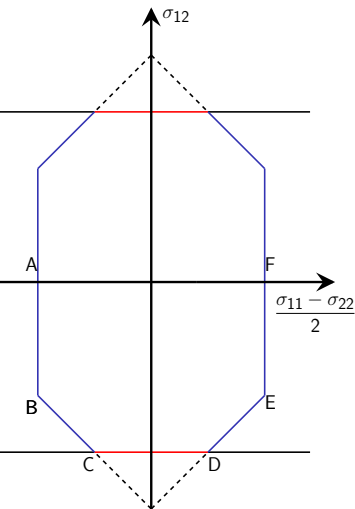
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

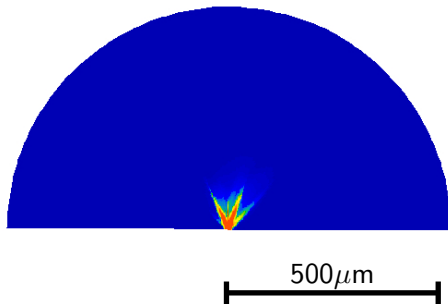
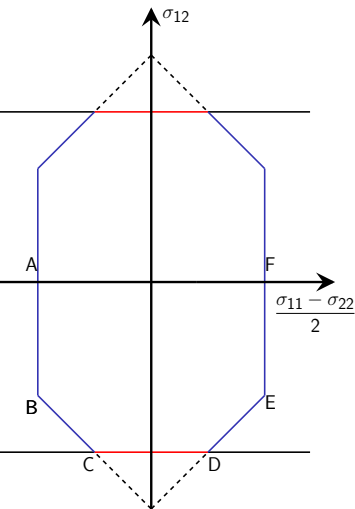
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

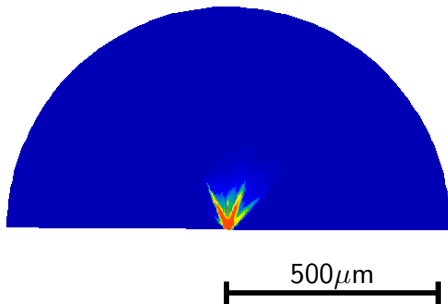
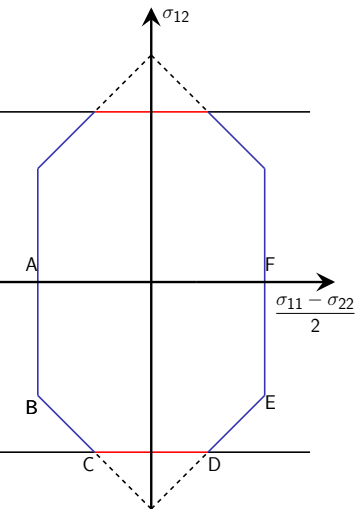
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

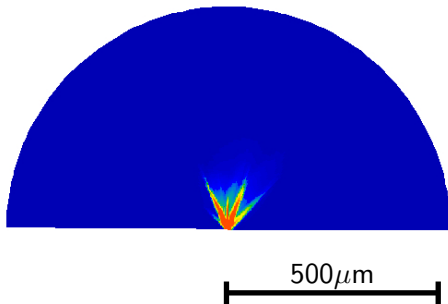
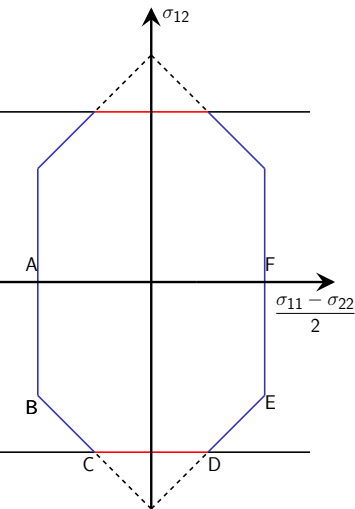
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

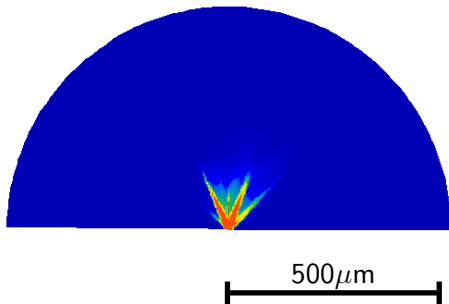
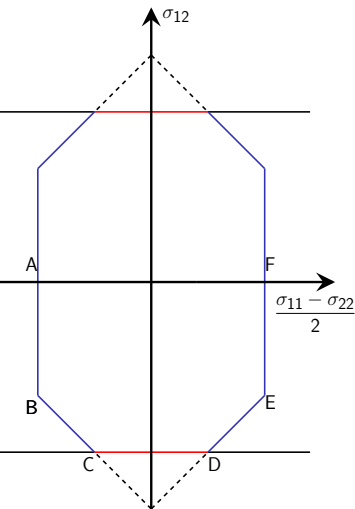
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

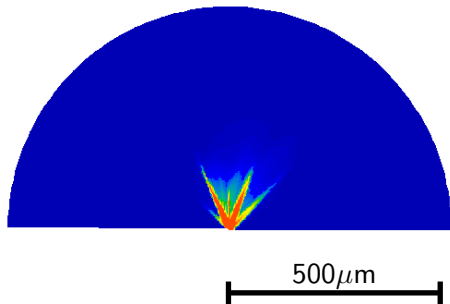
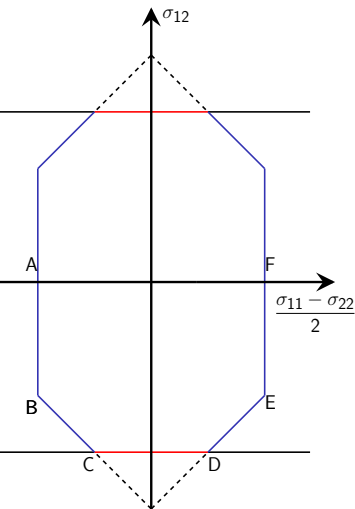
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

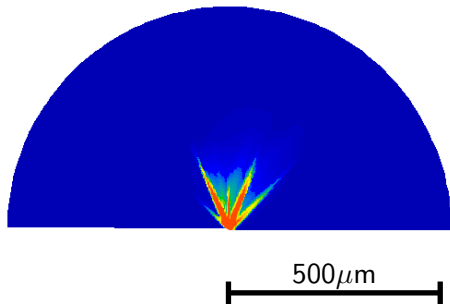
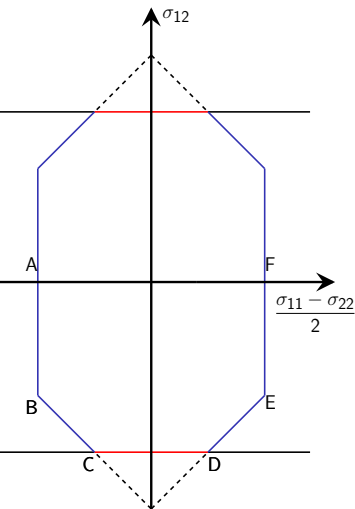
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

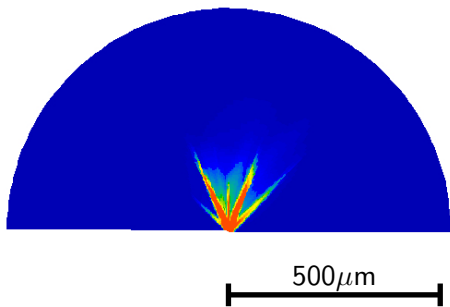
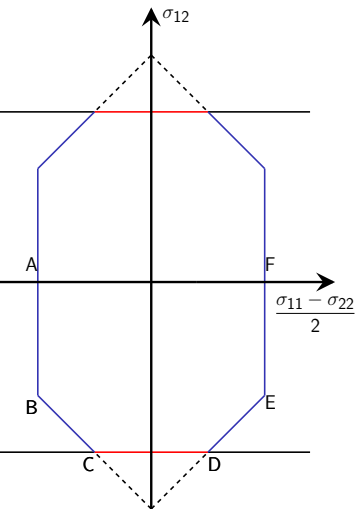
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

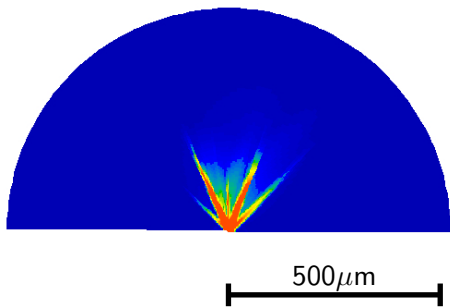
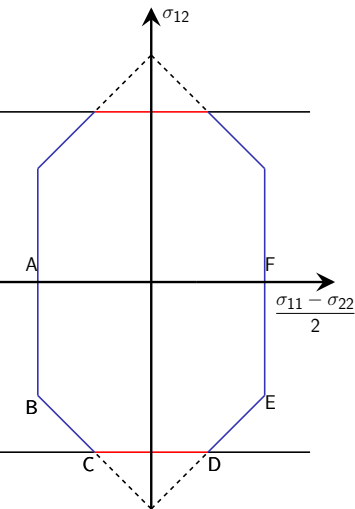
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

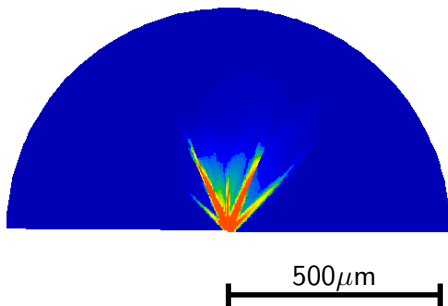
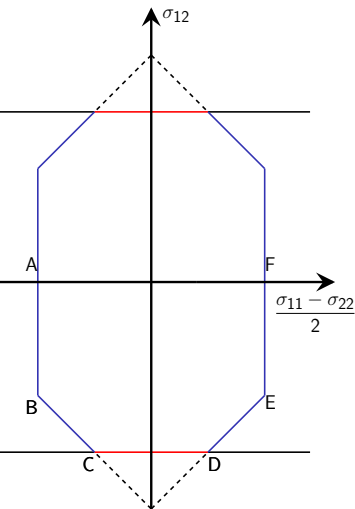
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

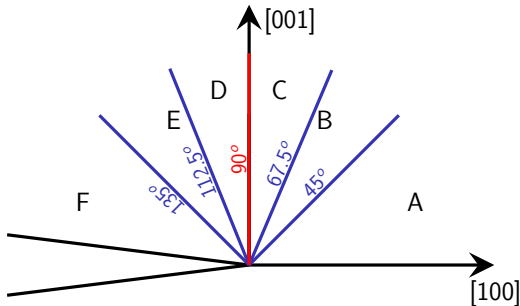
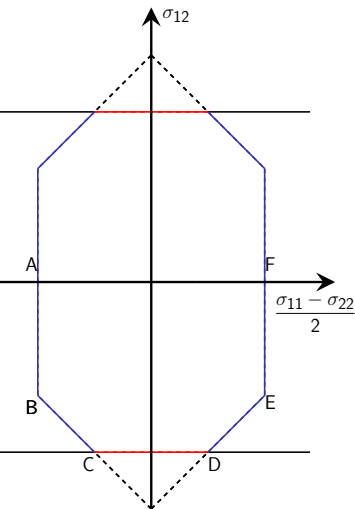
Step 2

▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

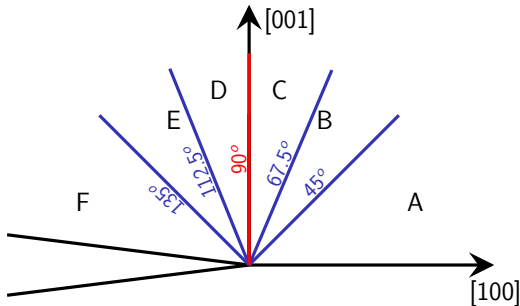
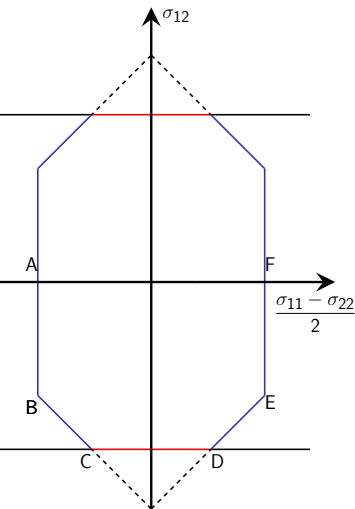
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

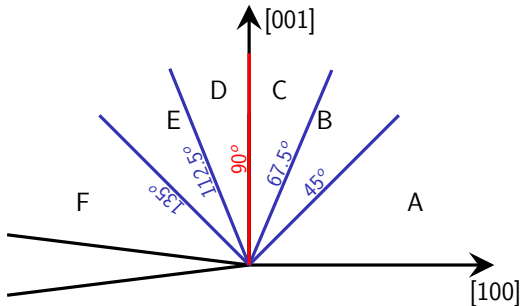
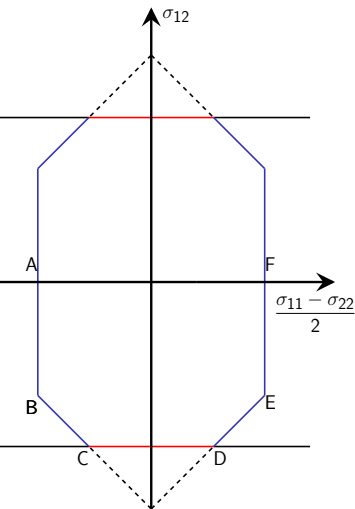
Step 2

▶▶ End

Application to a new orientation

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$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

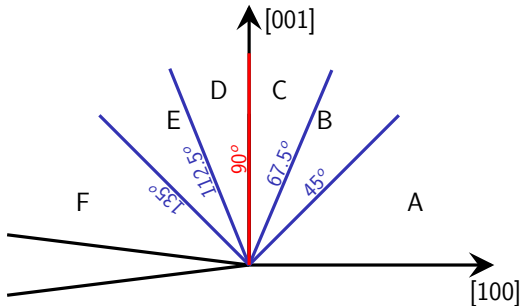
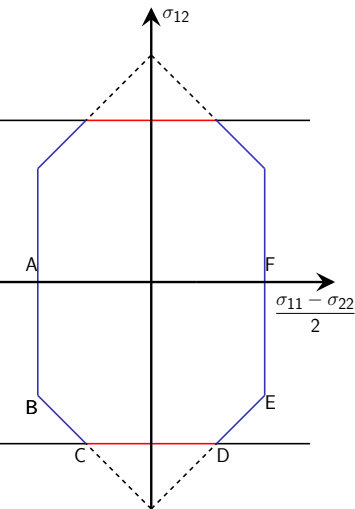
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

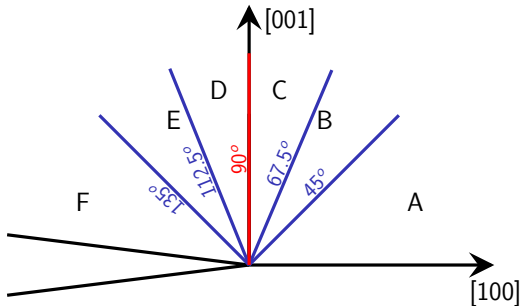
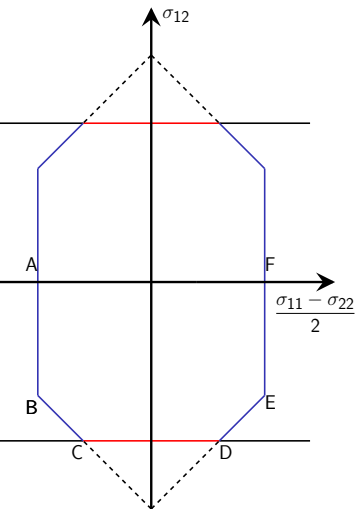
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

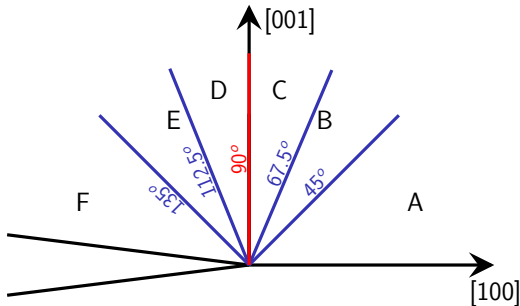
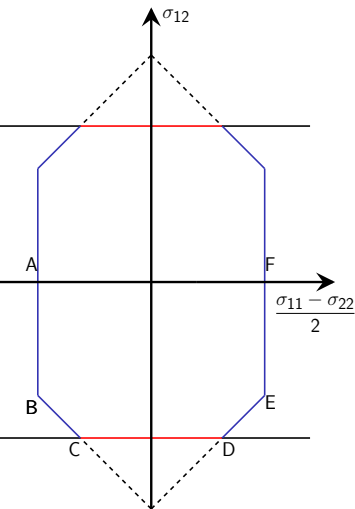
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

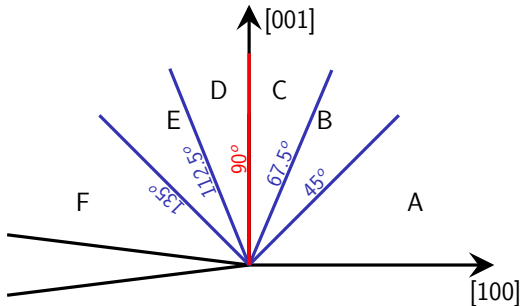
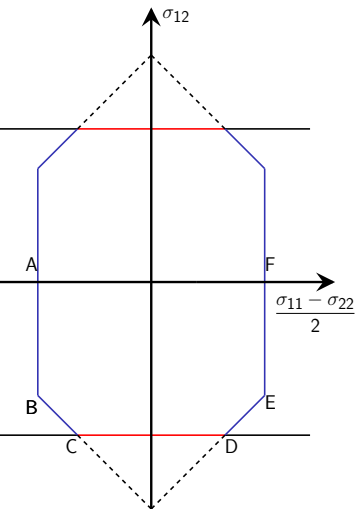
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

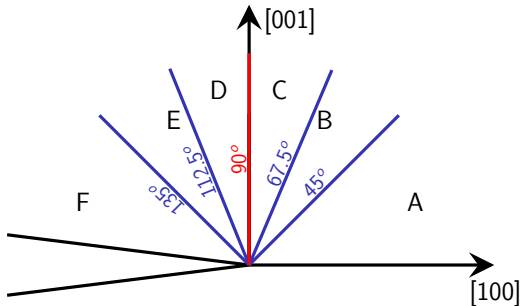
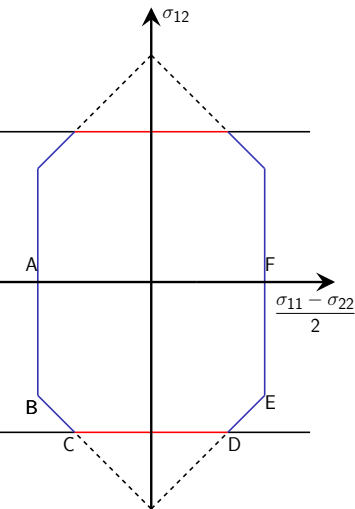
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$

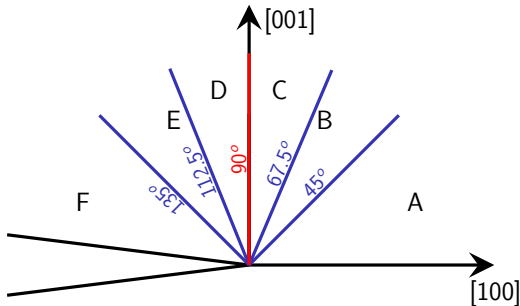
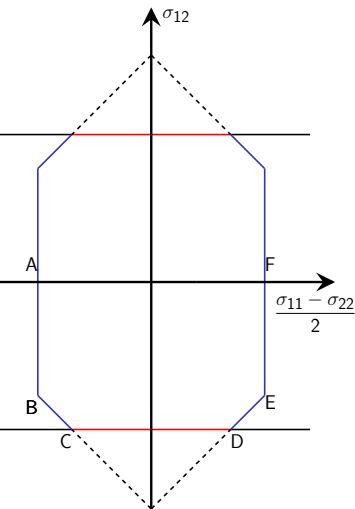


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

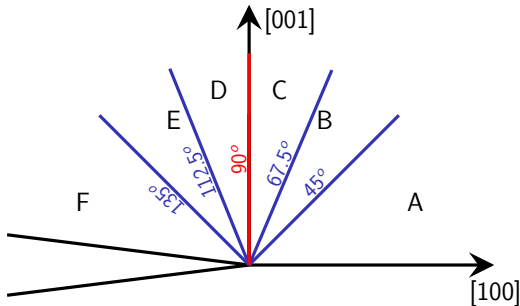
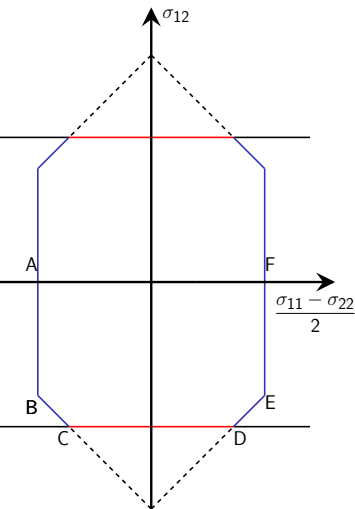
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

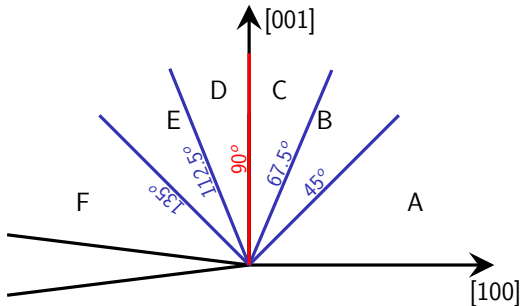
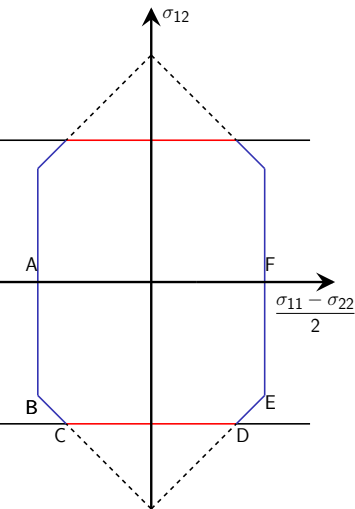
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$

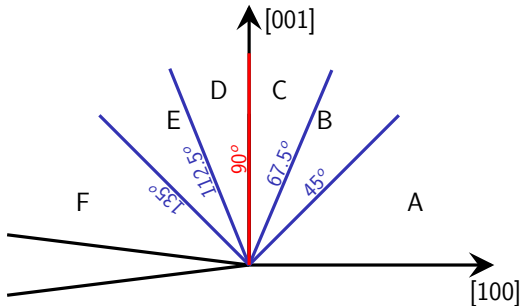
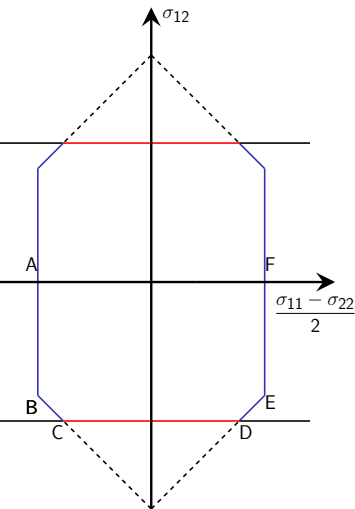


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$

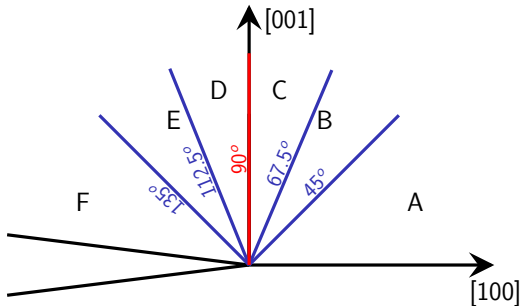
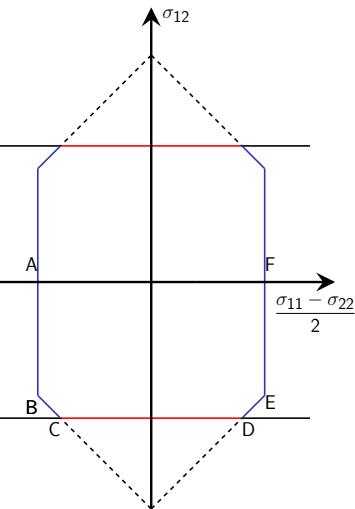


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

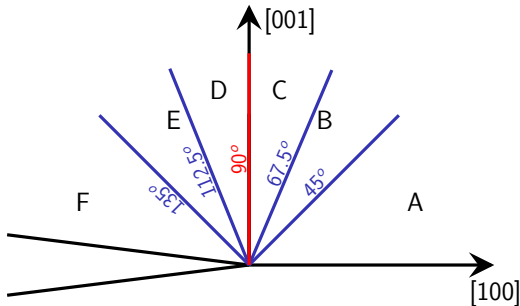
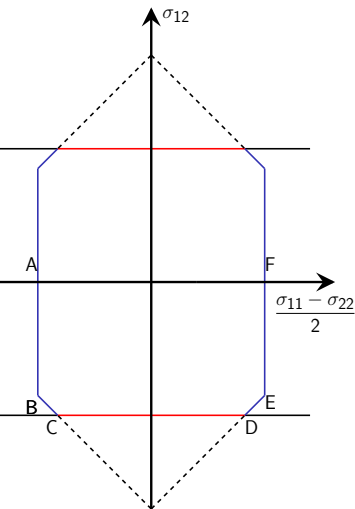
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

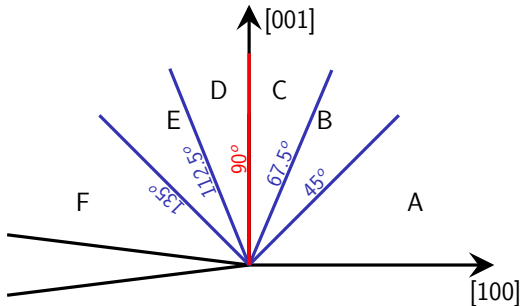
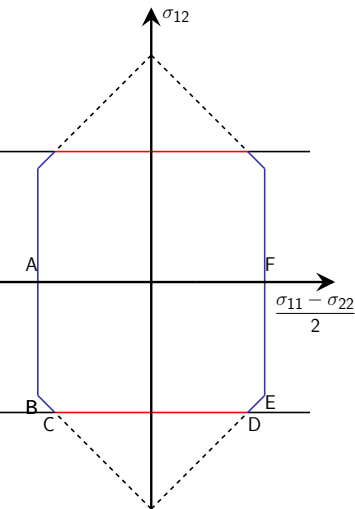
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

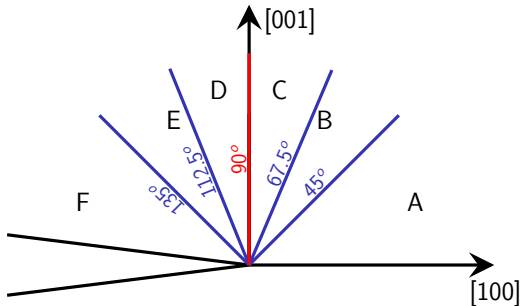
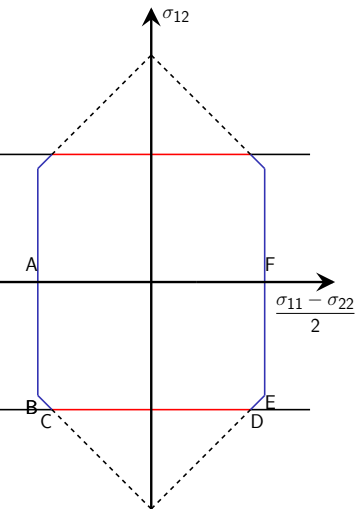
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

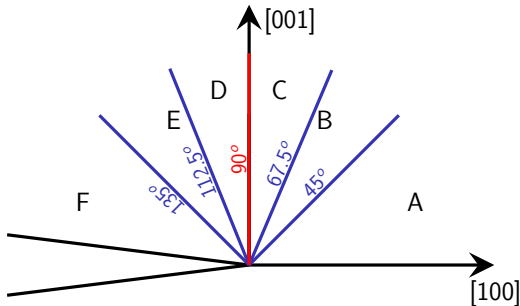
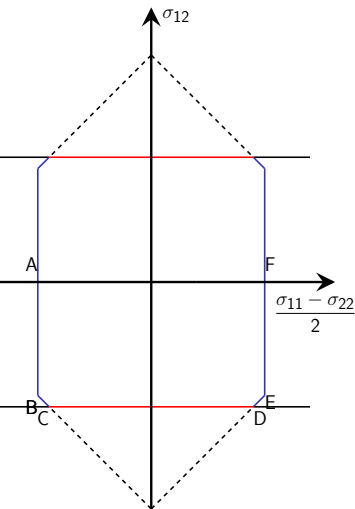
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$

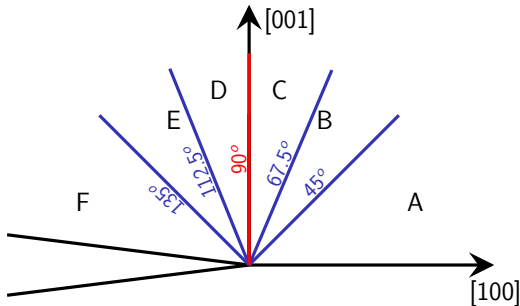
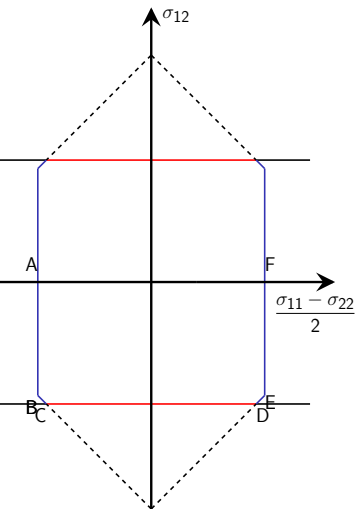


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

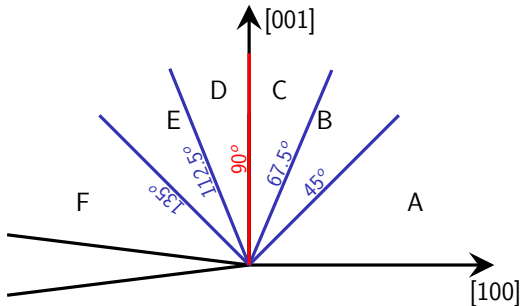
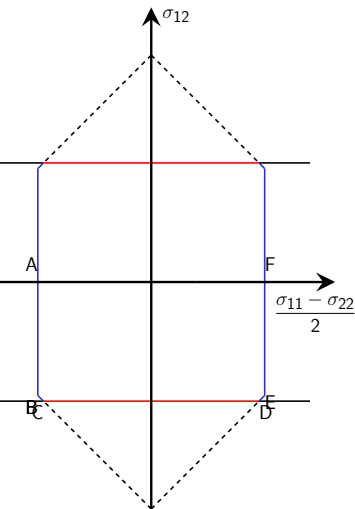
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$

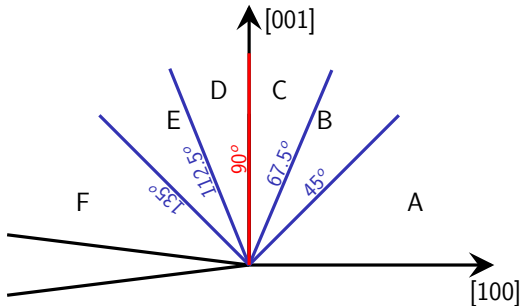
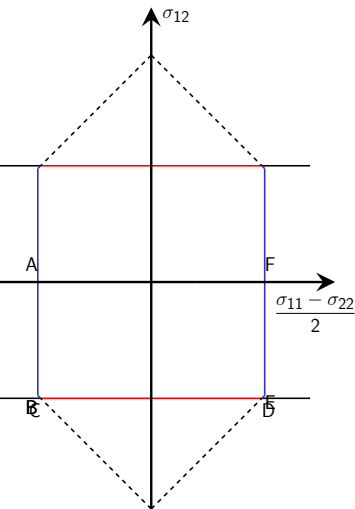


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\frac{\sqrt{3}}{2} \leq \rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \sqrt{3}$$



◀ Start

Step 1

▶ Animation

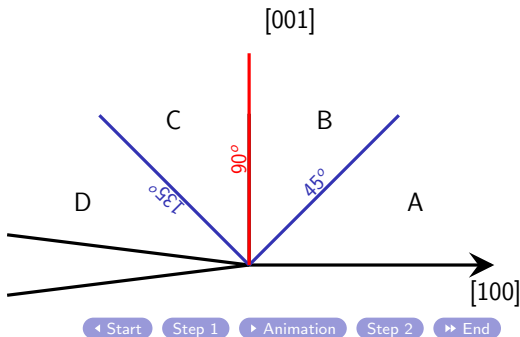
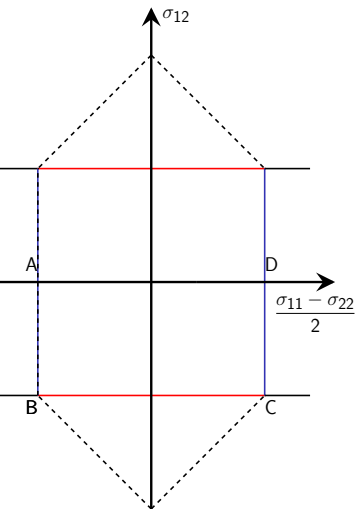
Step 2

▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

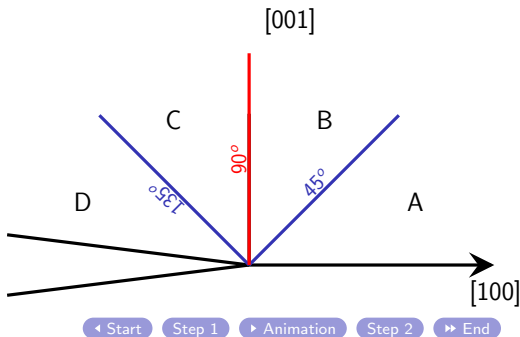
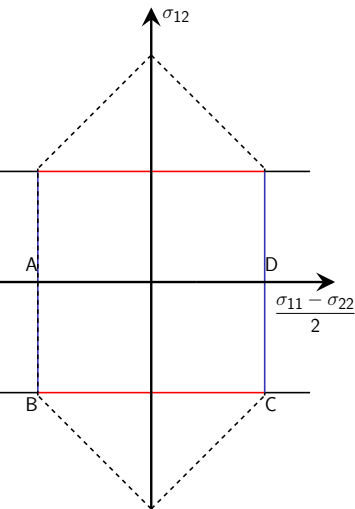
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$



Application to a new orientation

Orientation $C \rightarrow (001)[100]$

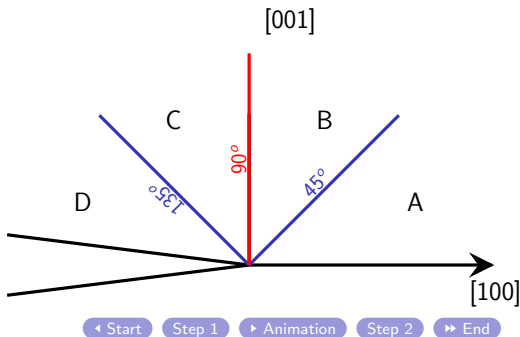
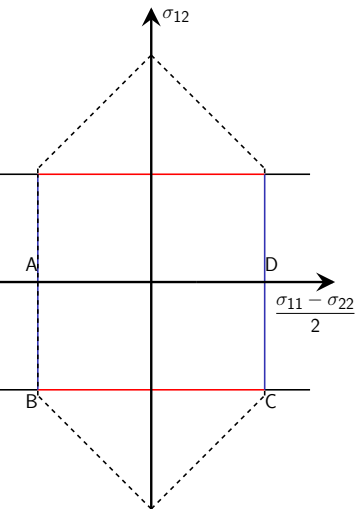
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$



Application to a new orientation

Orientation $C \rightarrow (001)[100]$

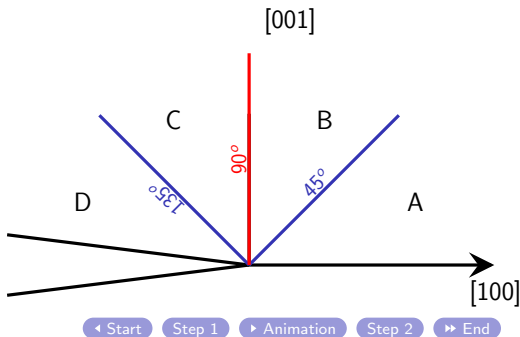
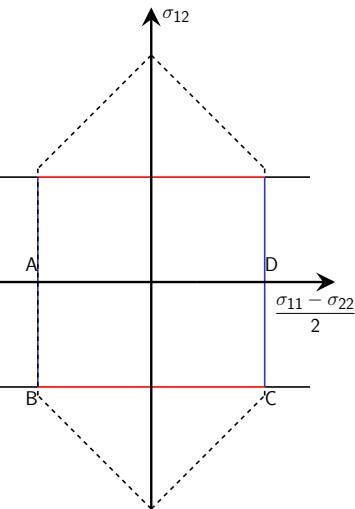
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$



Application to a new orientation

Orientation $C \rightarrow (001)[100]$

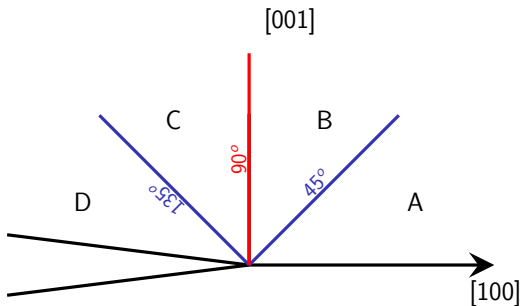
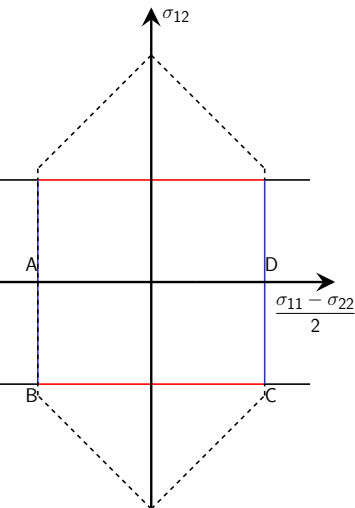
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$



Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$

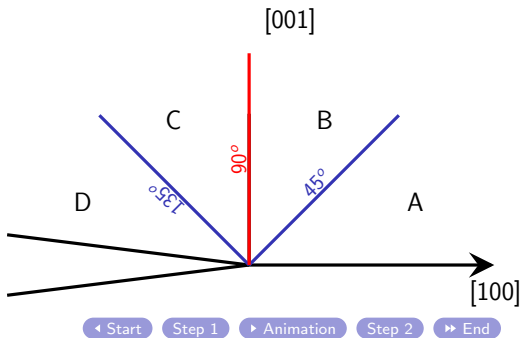
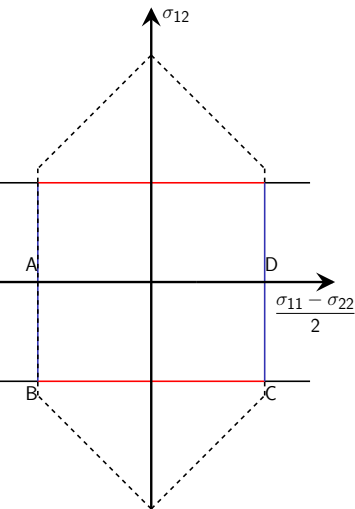


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

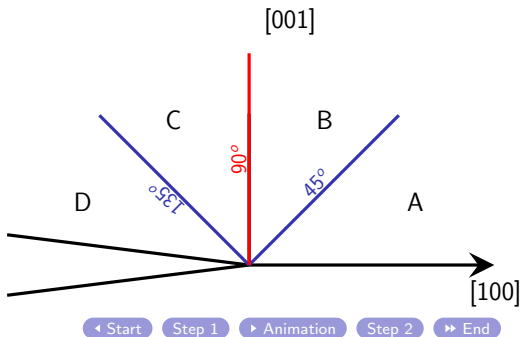
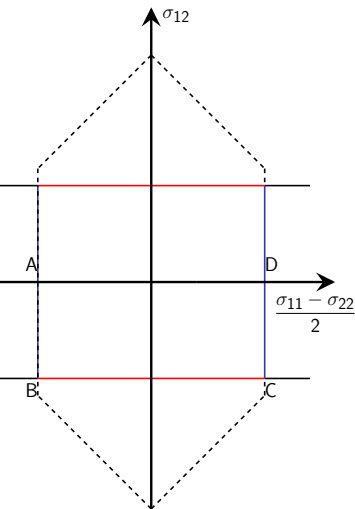
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$



Application to a new orientation

Orientation $C \rightarrow (001)[100]$

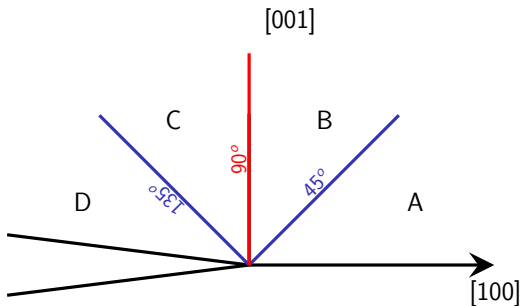
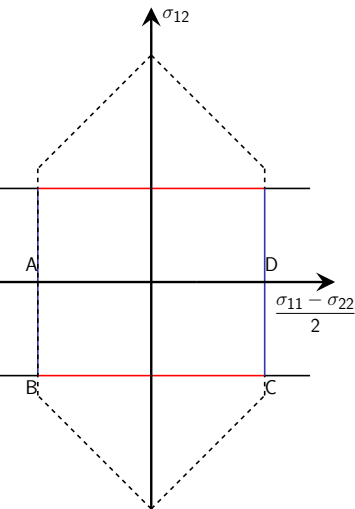
$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$



Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$

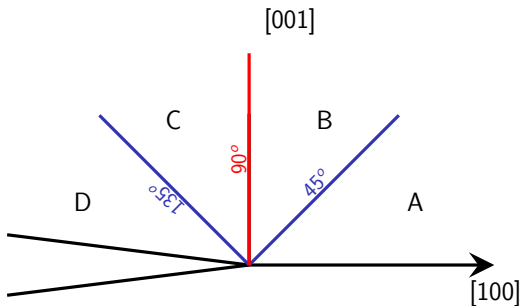
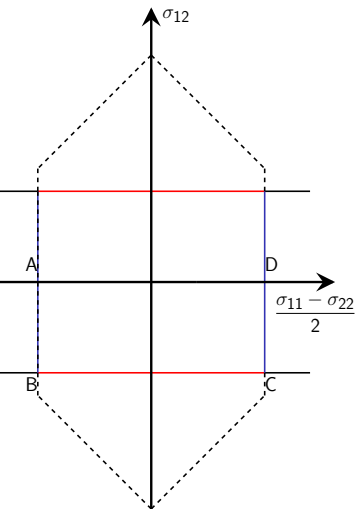


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$

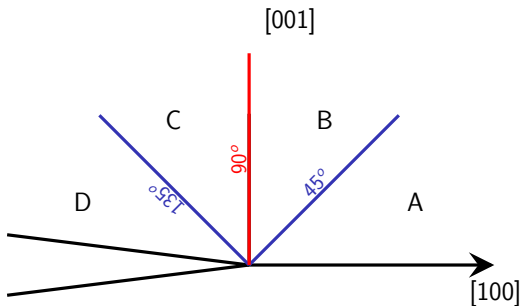
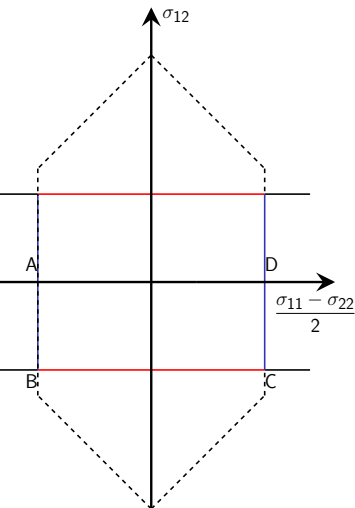


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$

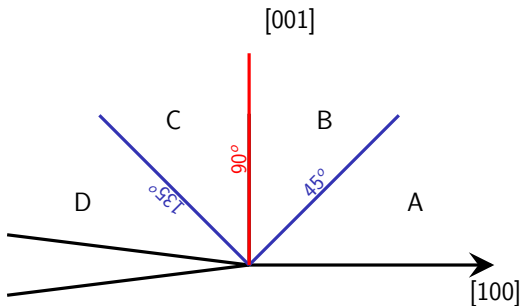
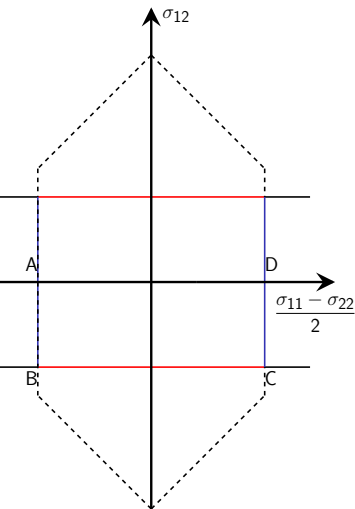


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation C \rightarrow (001)[100]

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$

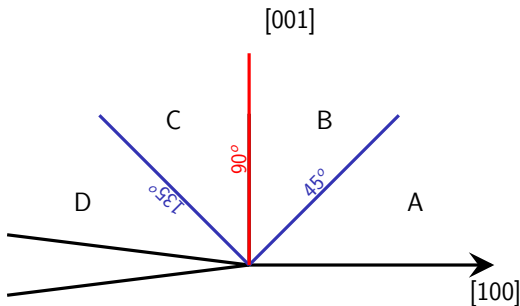
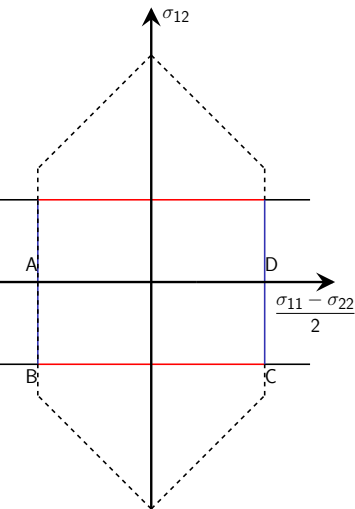


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$

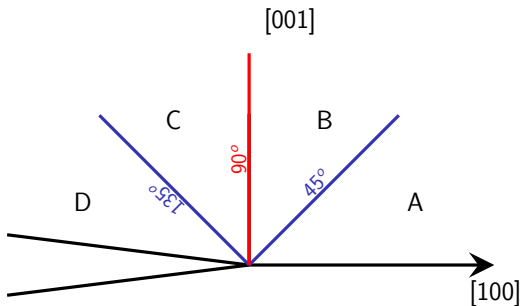
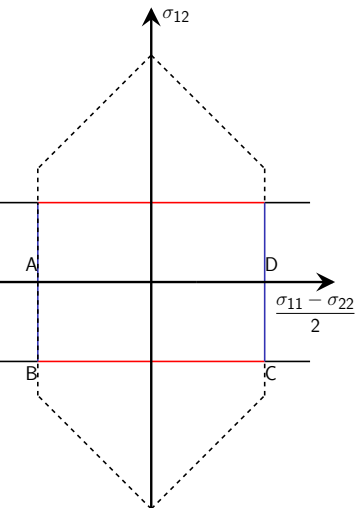


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$

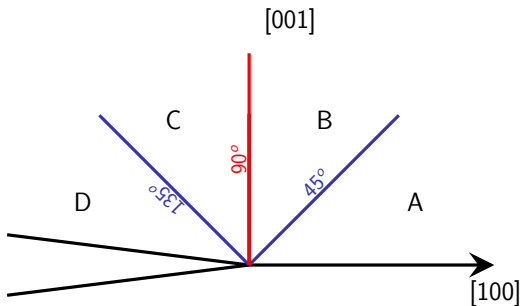
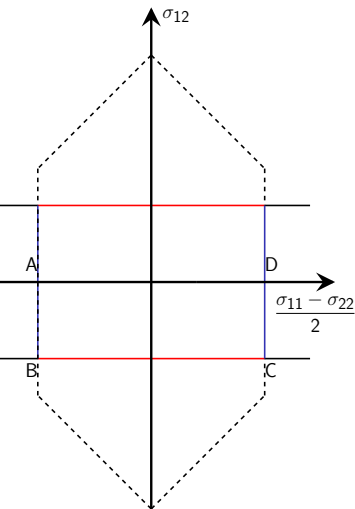


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$

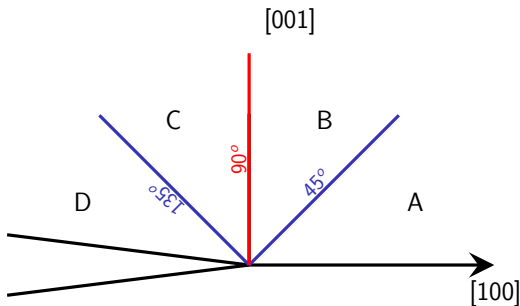
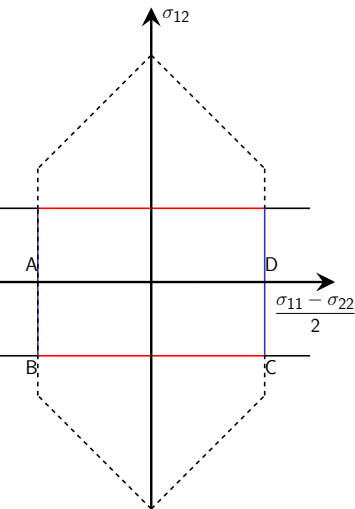


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$

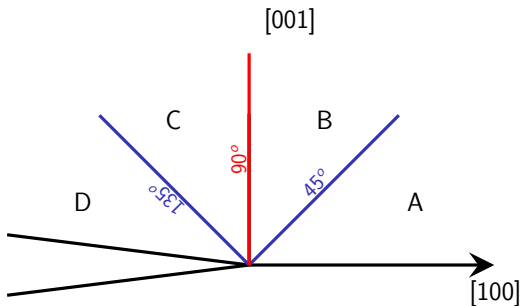
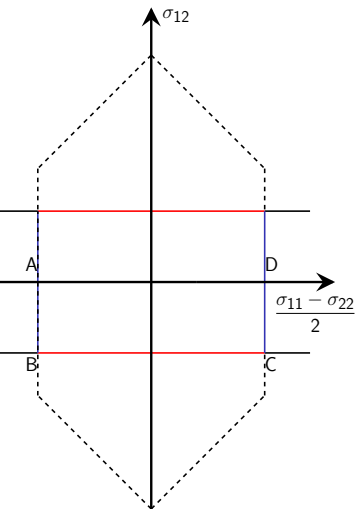


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$

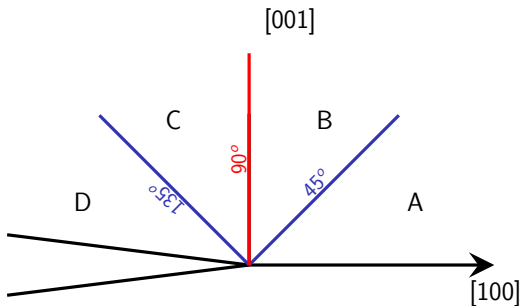
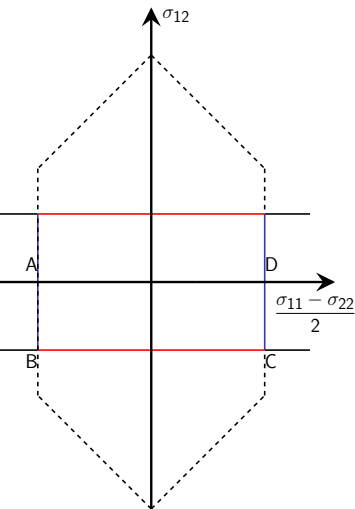


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$

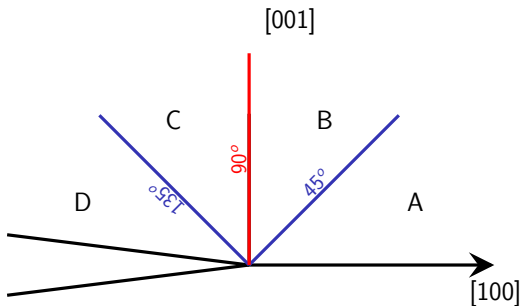
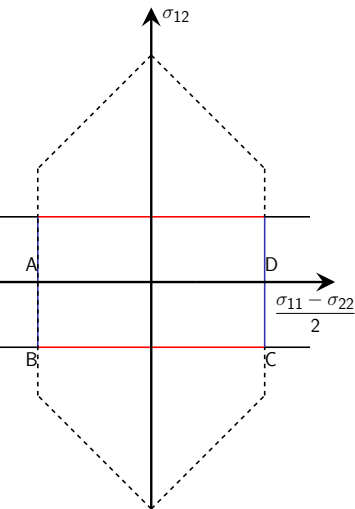


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$

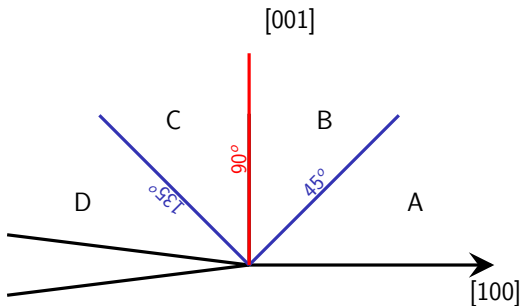
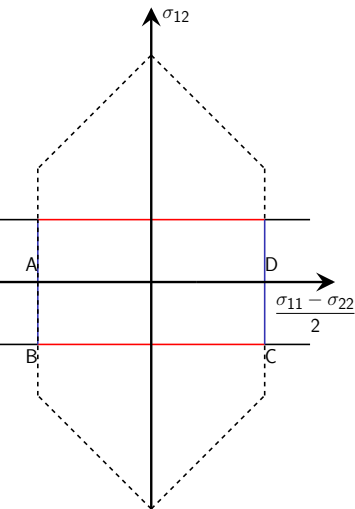


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$

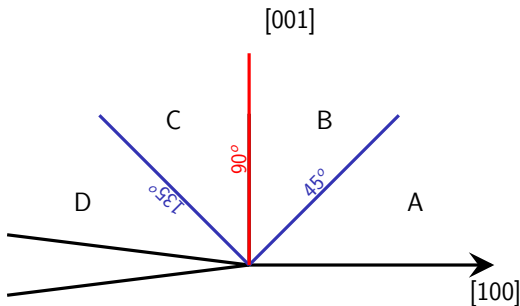
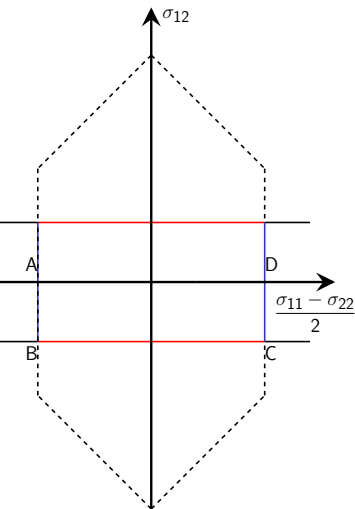


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$

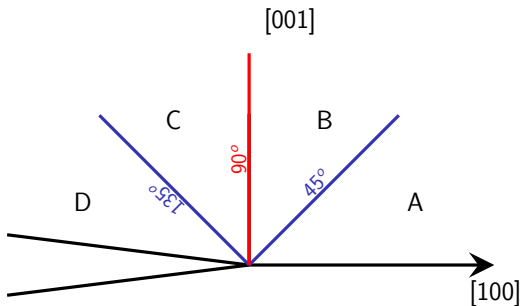
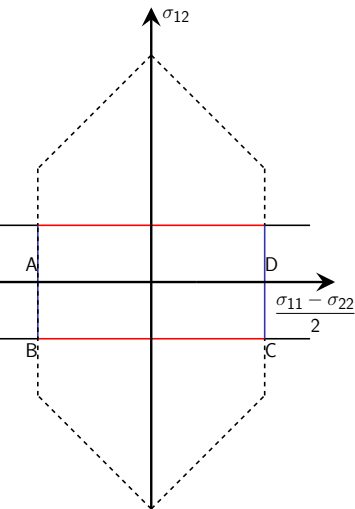


◀ Start Step 1 ▶ Animation Step 2 ▶▶ End

Application to a new orientation

Orientation $C \rightarrow (001)[100]$

$$\rho = \frac{\tau_{cub}}{\tau_{oc}} \leq \frac{\sqrt{3}}{2}$$



◀ Start

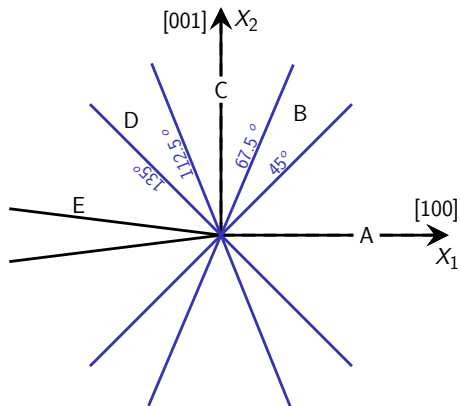
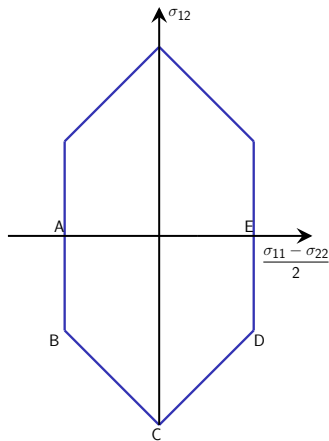
Step 1

▶ Animation

Step 2

▶▶ End

Extension to non-symmetrical crystal orientations

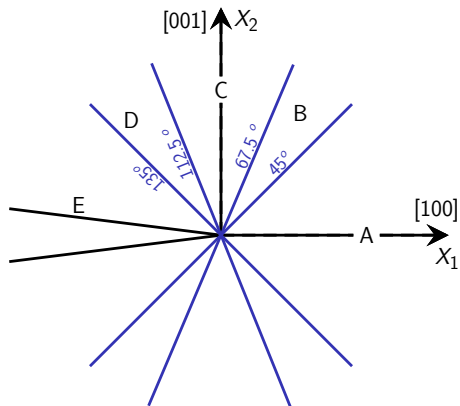
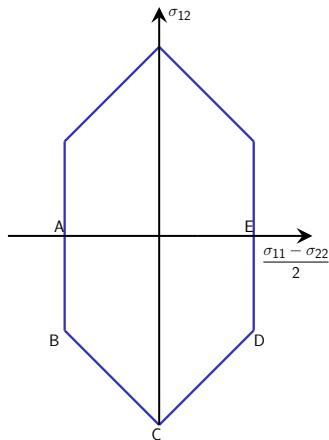


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

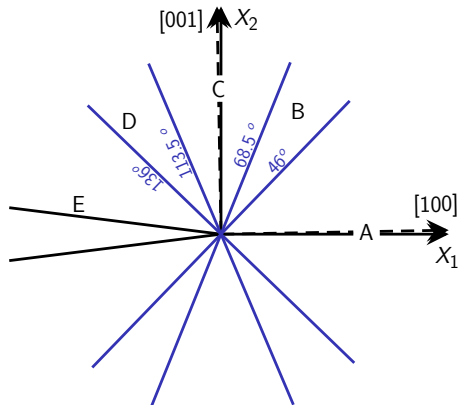
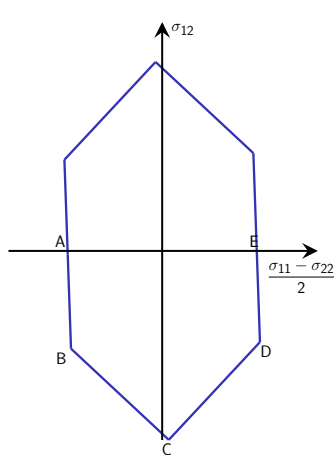


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

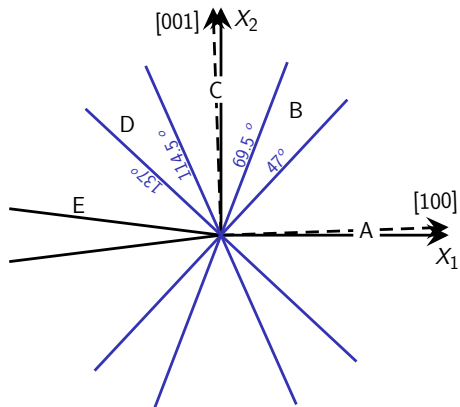
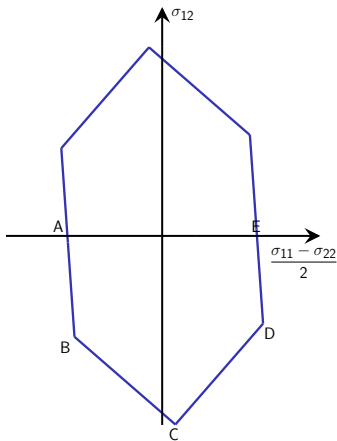


◀ Start

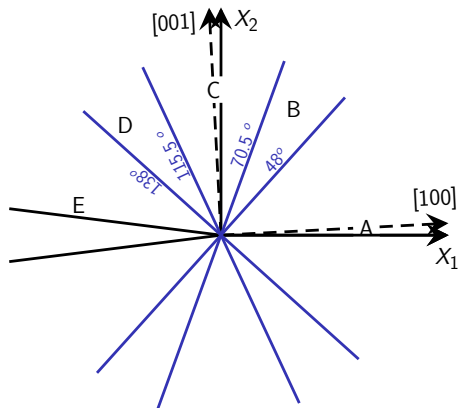
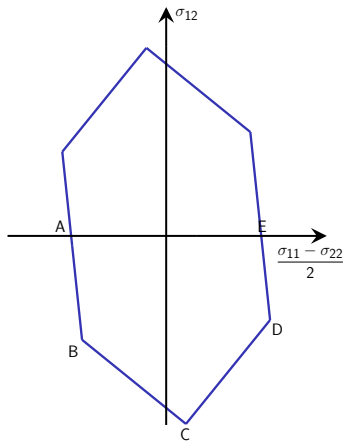
▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations



Extension to non-symmetrical crystal orientations

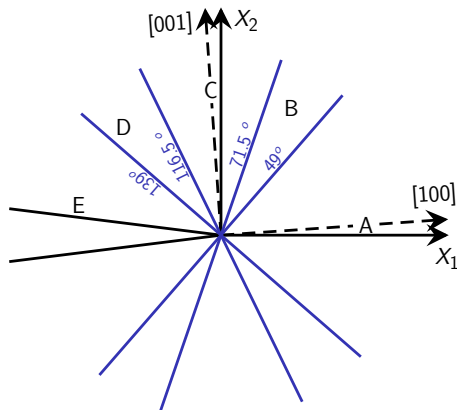
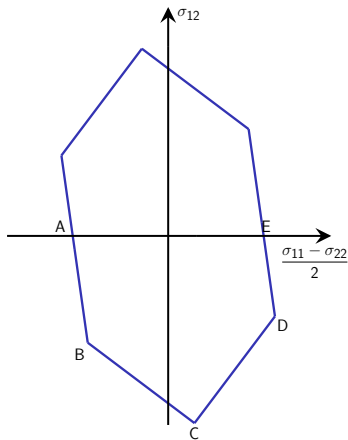


◀ Start

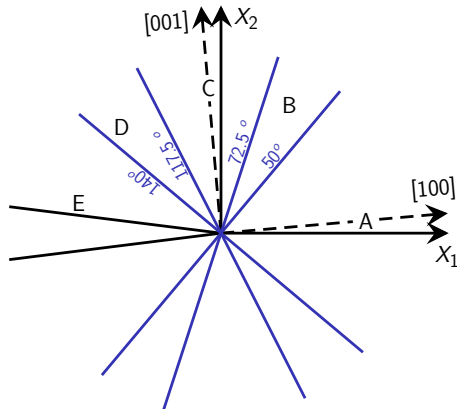
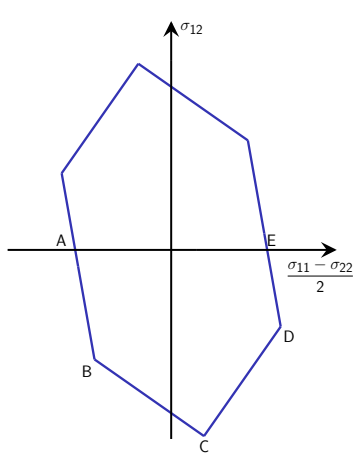
▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations



Extension to non-symmetrical crystal orientations

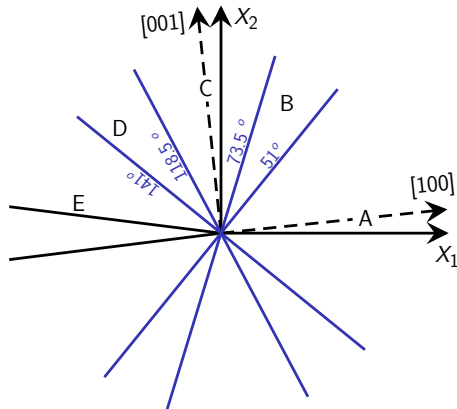
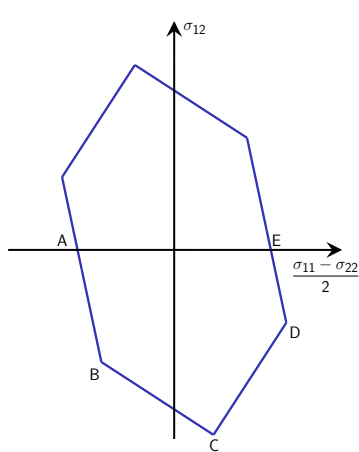


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

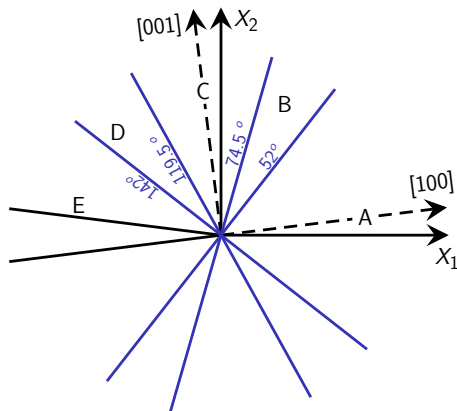
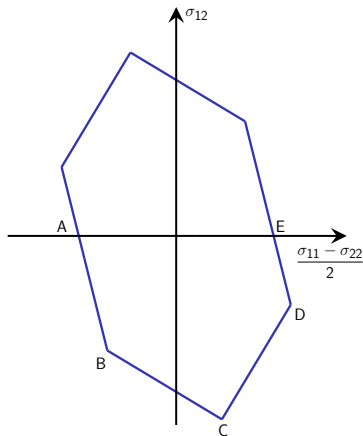


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

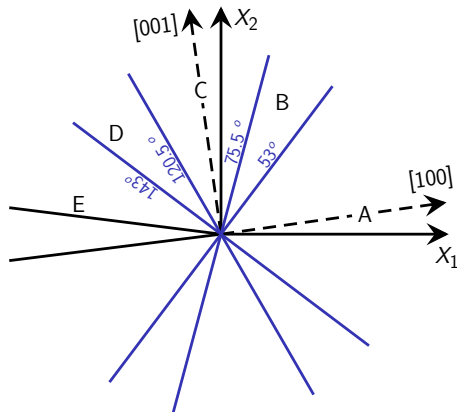
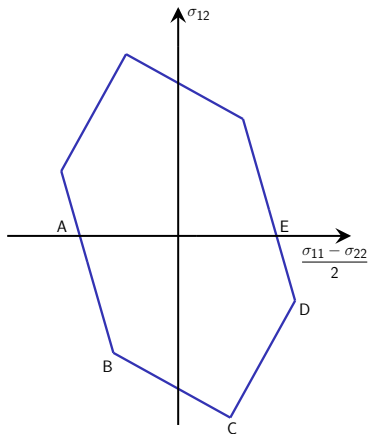


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

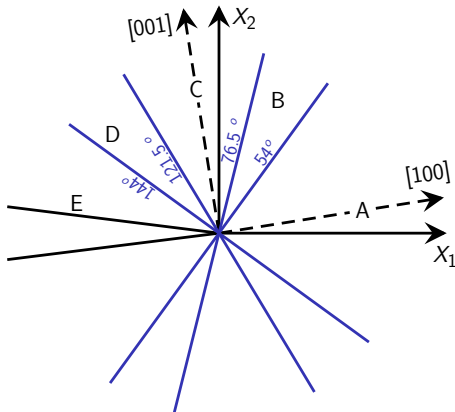
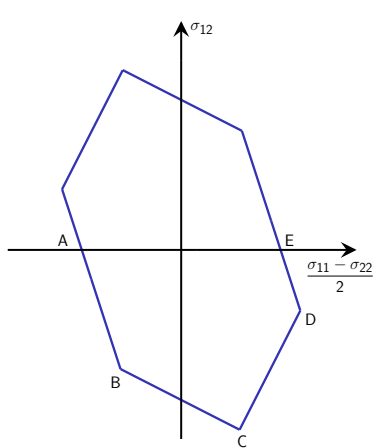


◀ Start

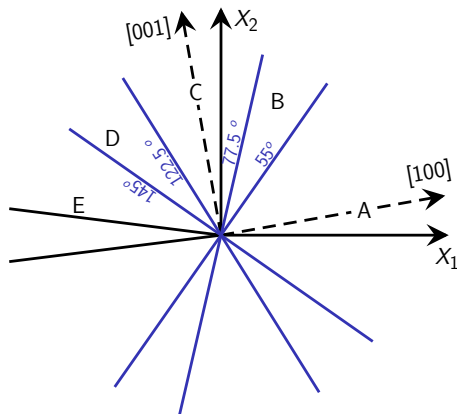
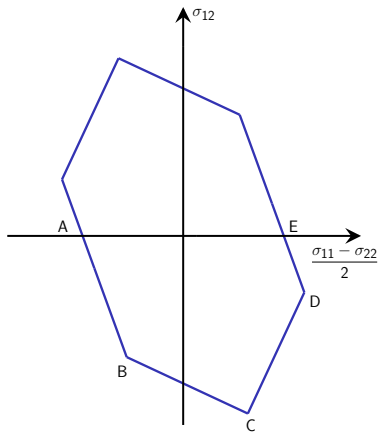
▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations



Extension to non-symmetrical crystal orientations

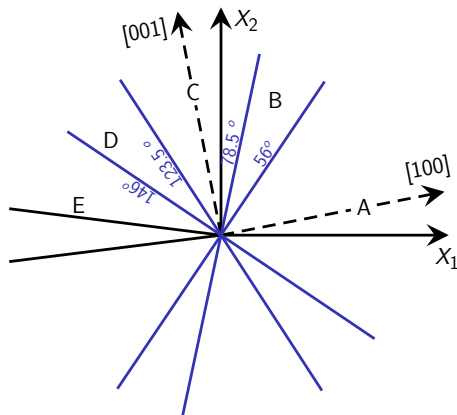
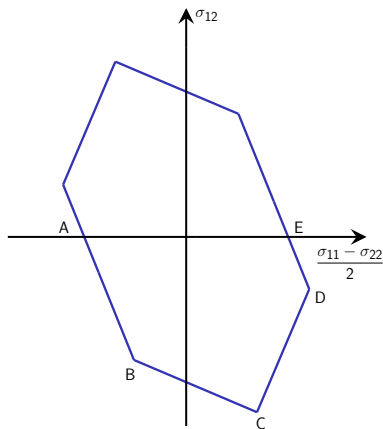


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

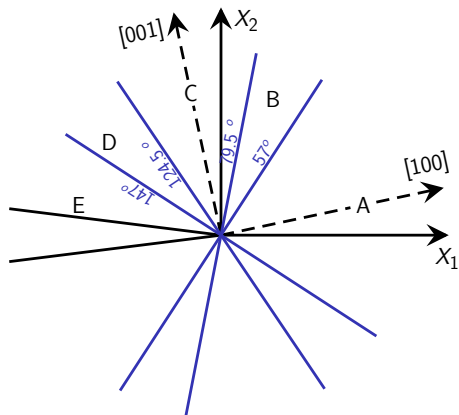
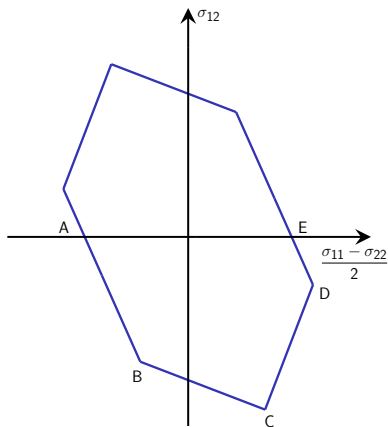


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

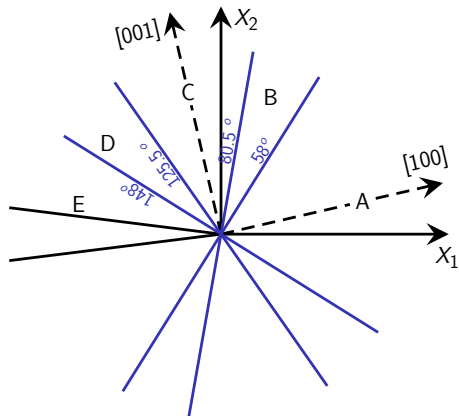
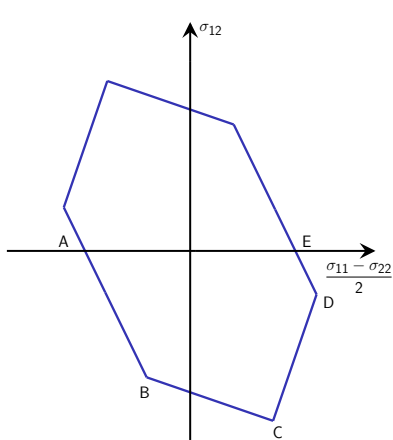


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

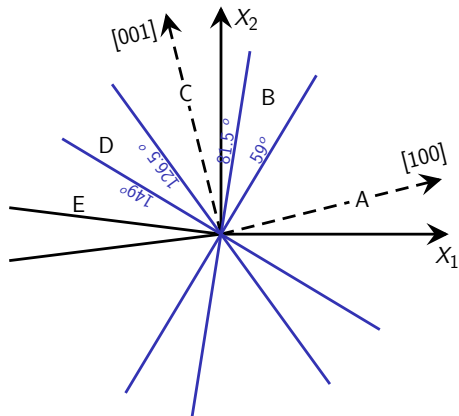
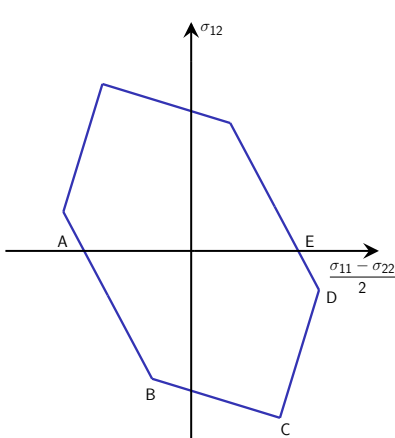


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

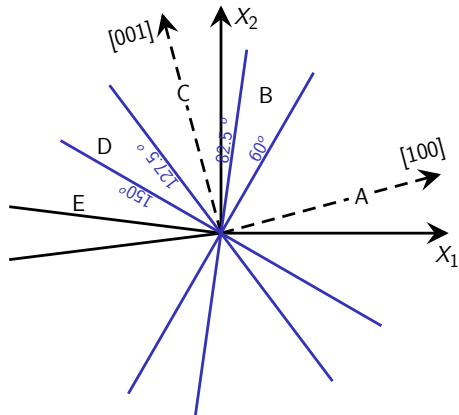
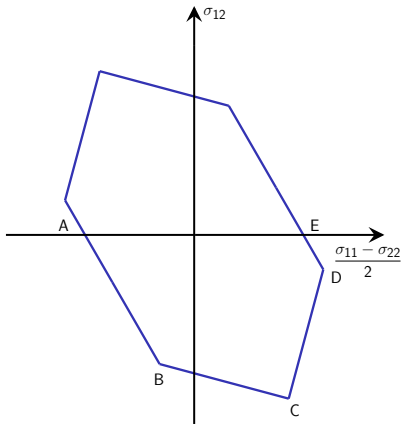


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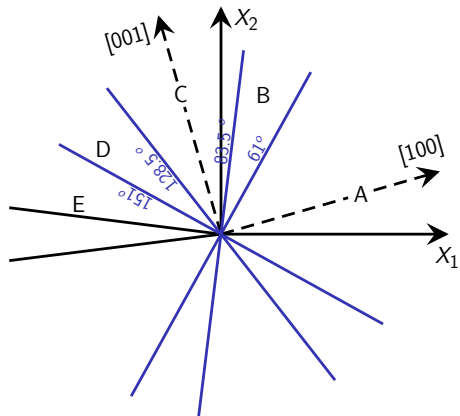
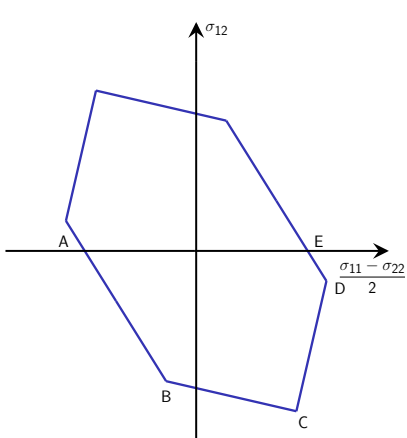
▶ Animation

▶▶ End

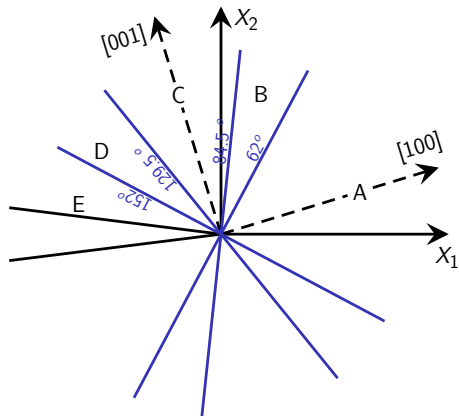
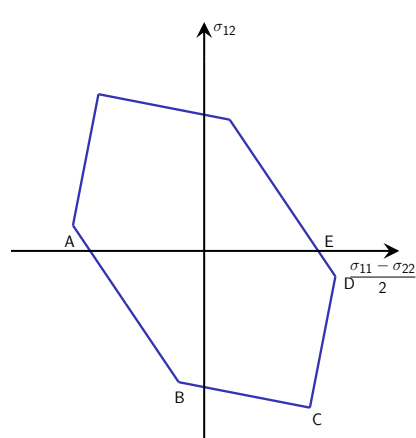
Extension to non-symmetrical crystal orientations



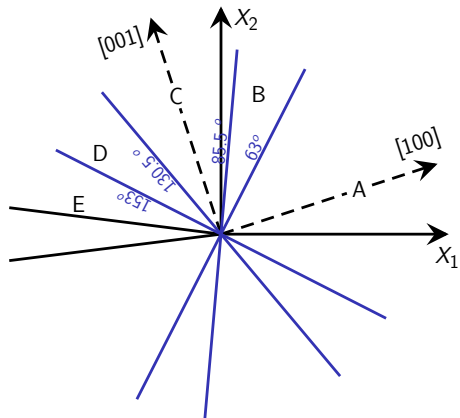
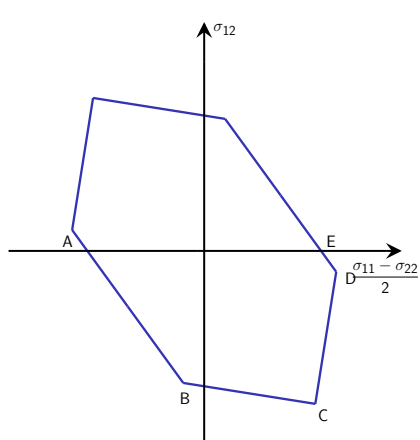
Extension to non-symmetrical crystal orientations



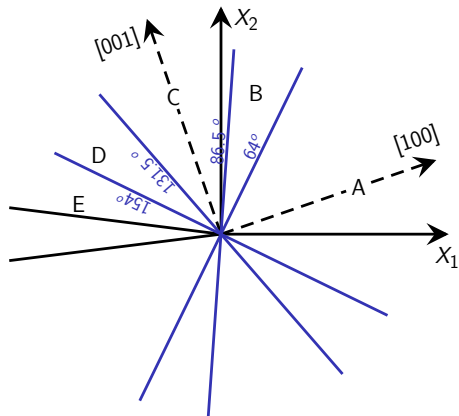
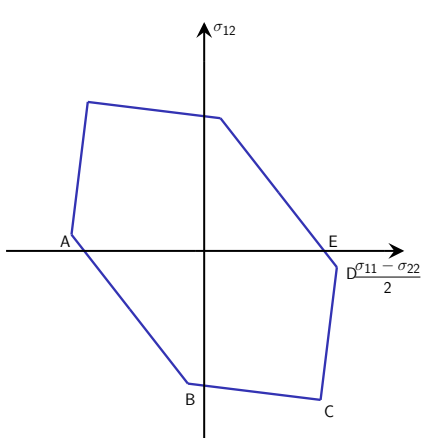
Extension to non-symmetrical crystal orientations



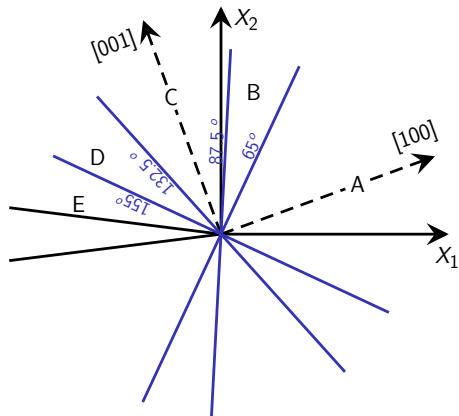
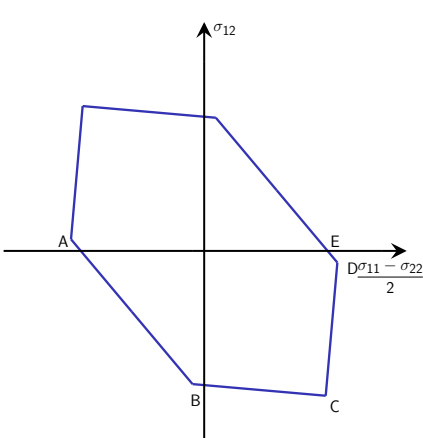
Extension to non-symmetrical crystal orientations



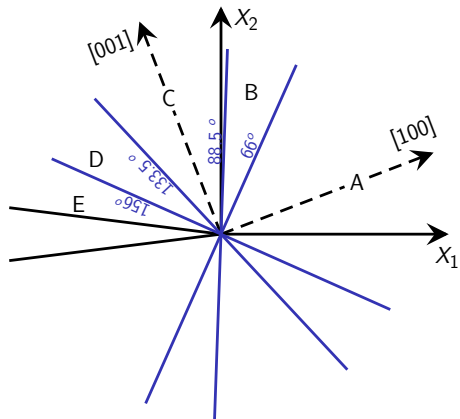
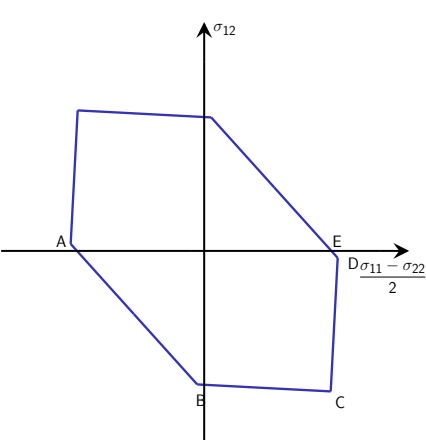
Extension to non-symmetrical crystal orientations



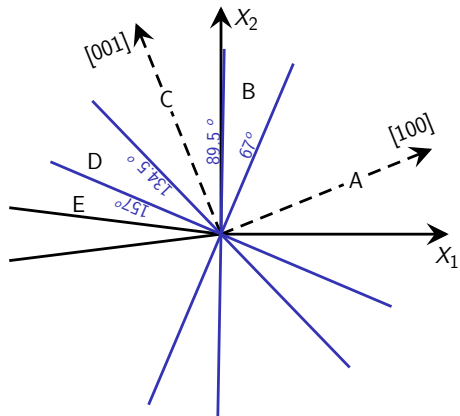
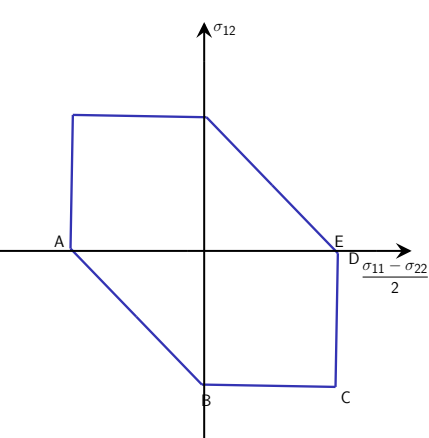
Extension to non-symmetrical crystal orientations



Extension to non-symmetrical crystal orientations



Extension to non-symmetrical crystal orientations

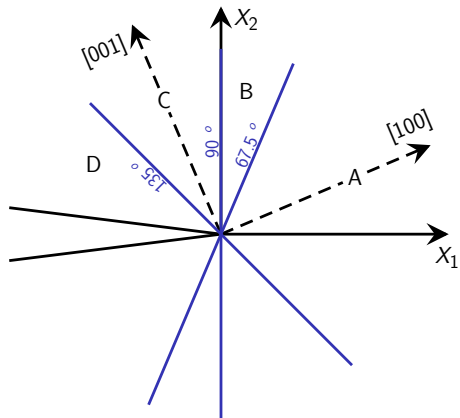
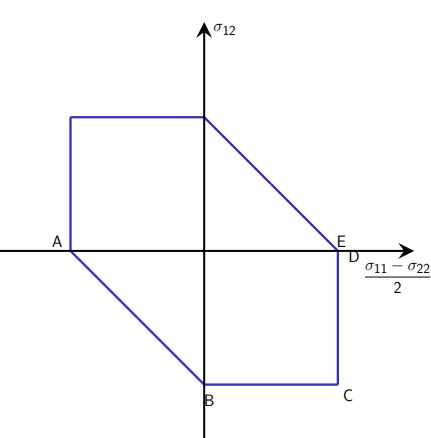


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

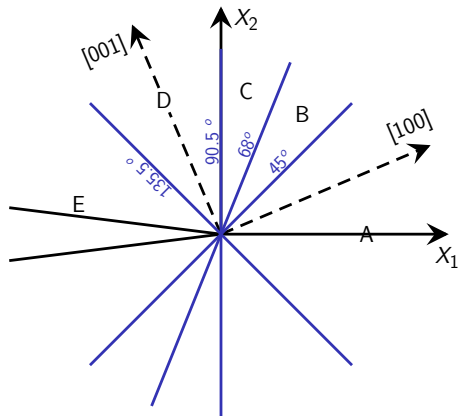
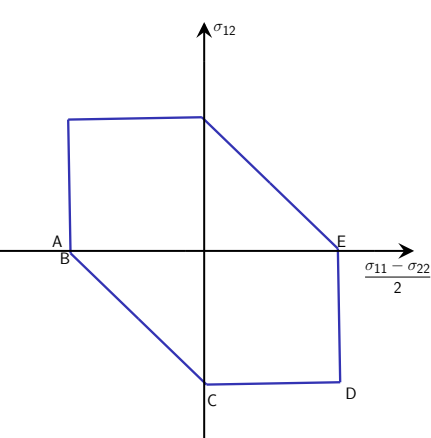


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

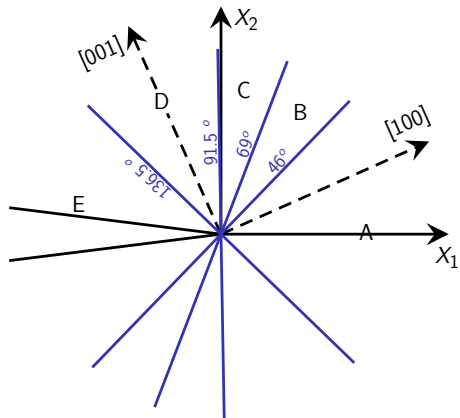
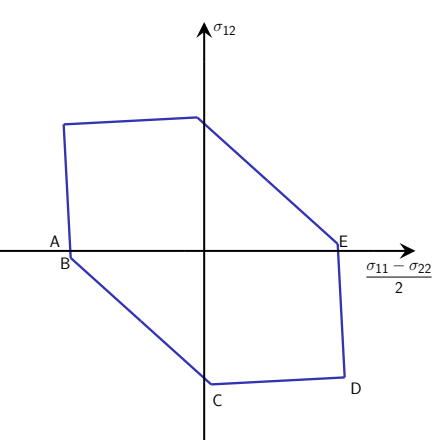


◀ Start

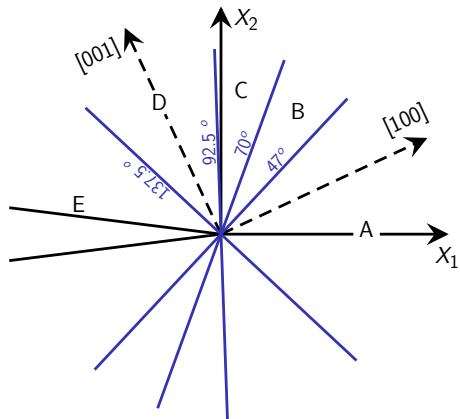
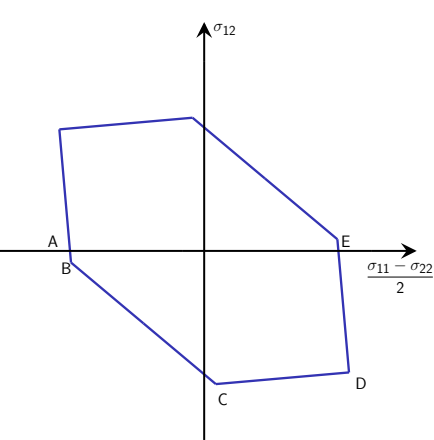
▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations



Extension to non-symmetrical crystal orientations

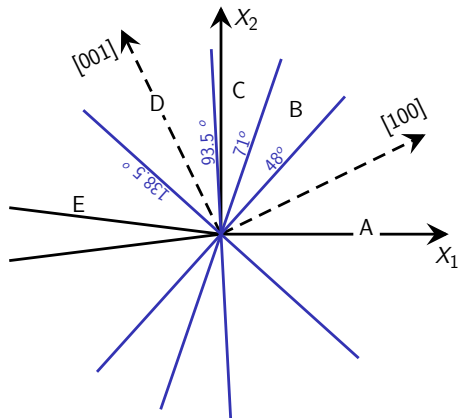
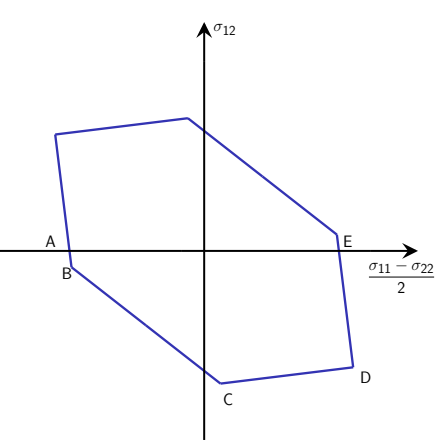


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

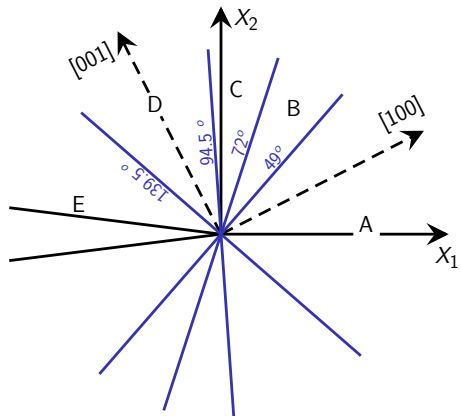
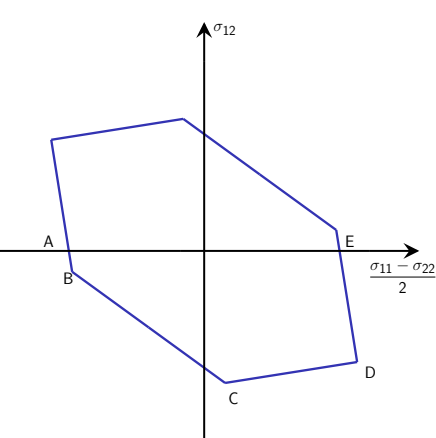


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

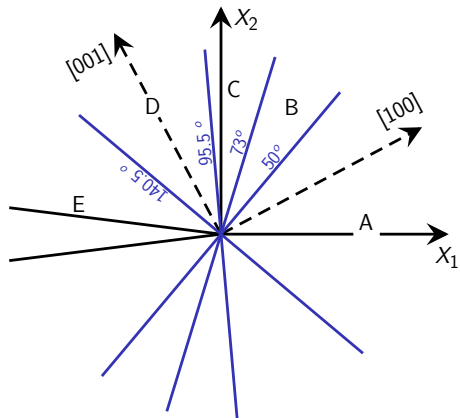
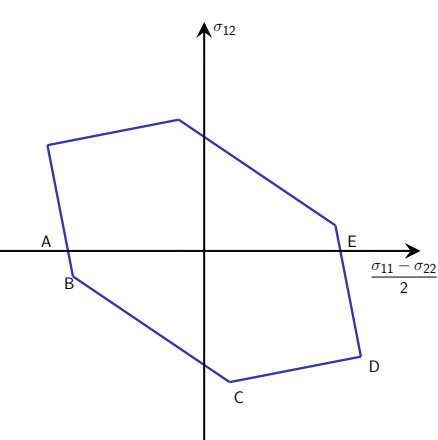


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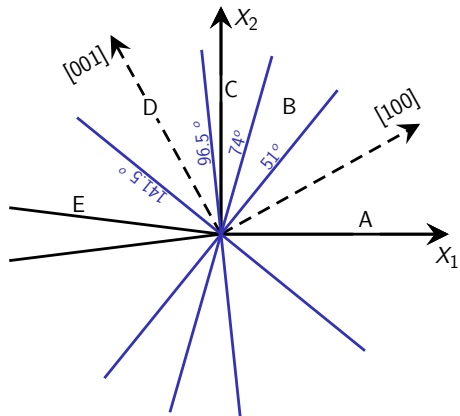
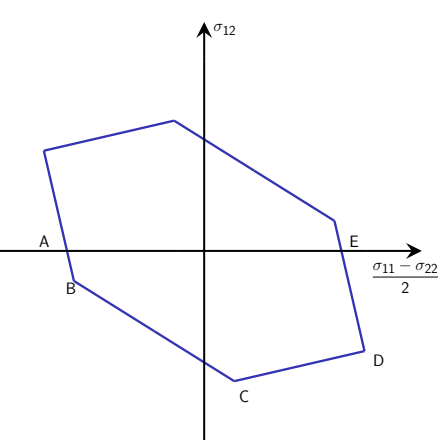
▶ Animation

▶▶ End

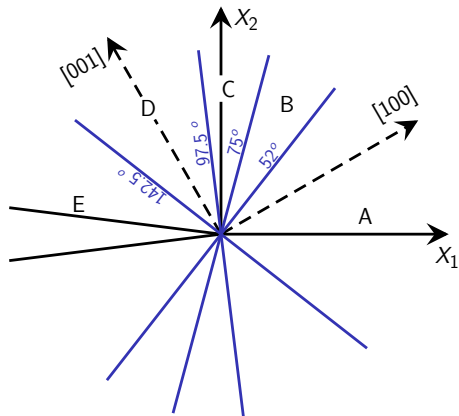
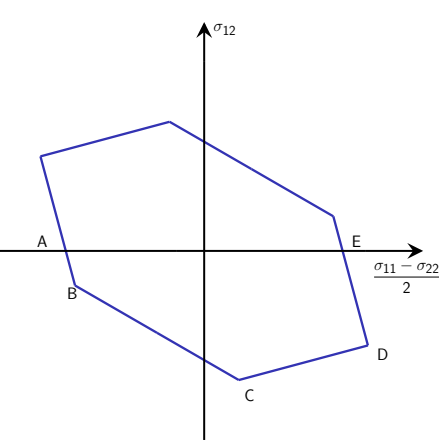
Extension to non-symmetrical crystal orientations



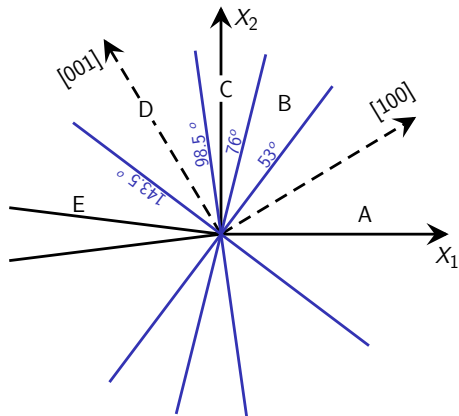
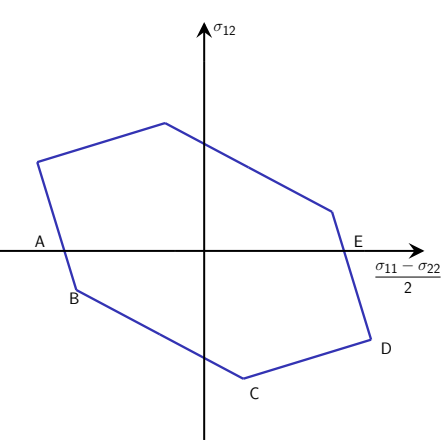
Extension to non-symmetrical crystal orientations



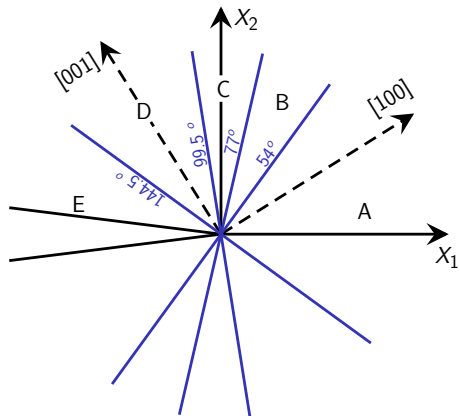
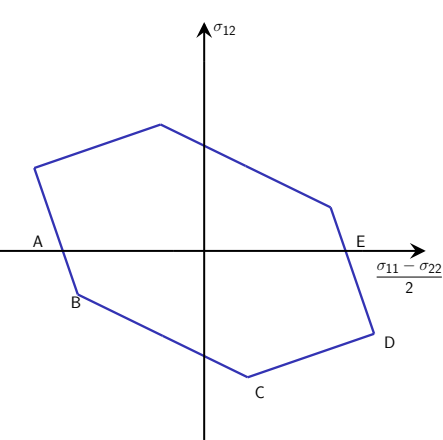
Extension to non-symmetrical crystal orientations



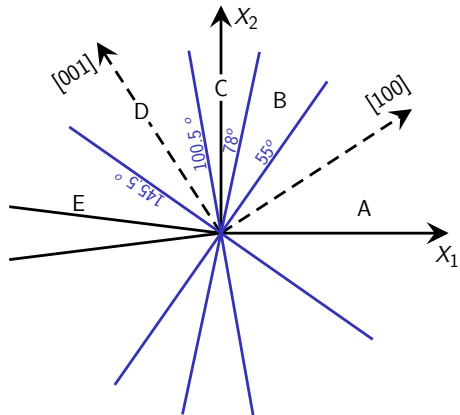
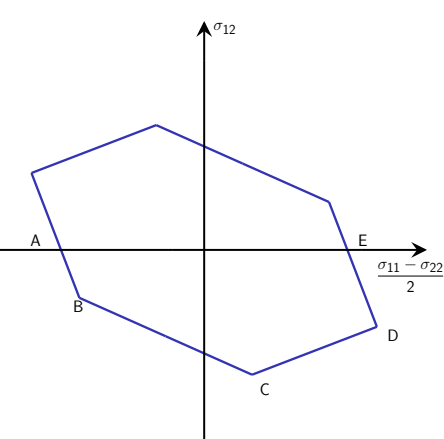
Extension to non-symmetrical crystal orientations



Extension to non-symmetrical crystal orientations



Extension to non-symmetrical crystal orientations

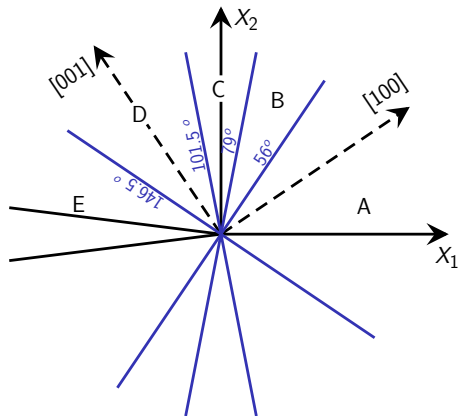
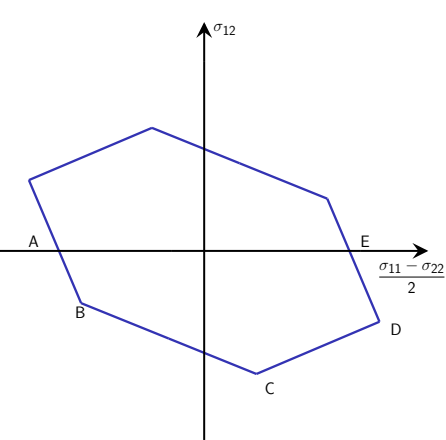


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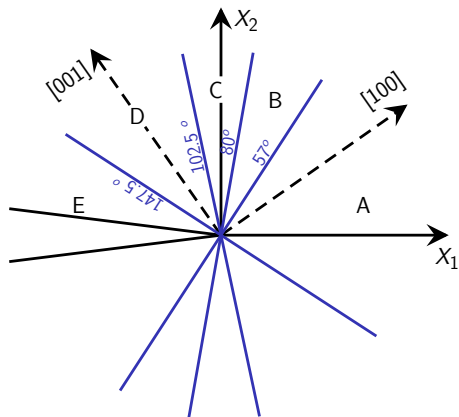
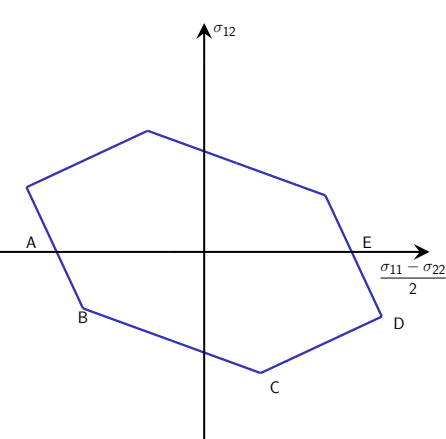
▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations



Extension to non-symmetrical crystal orientations

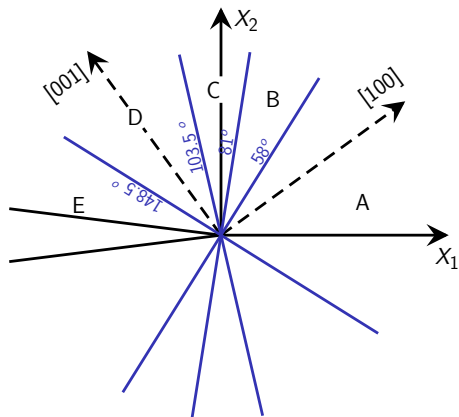
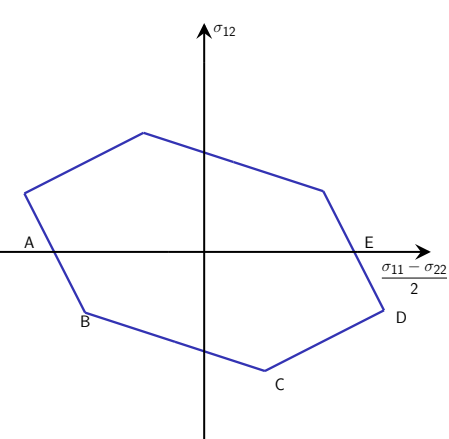


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

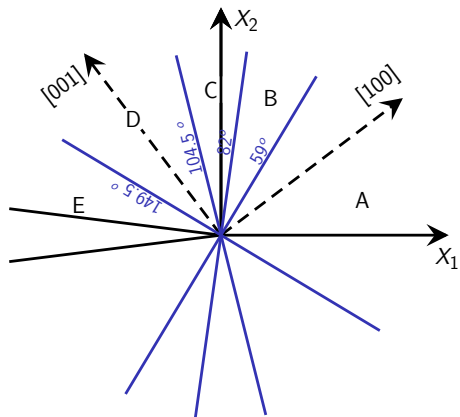
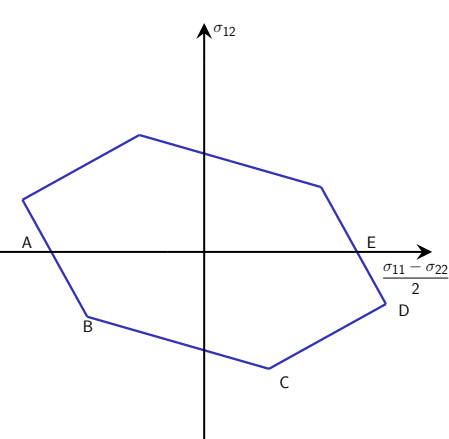


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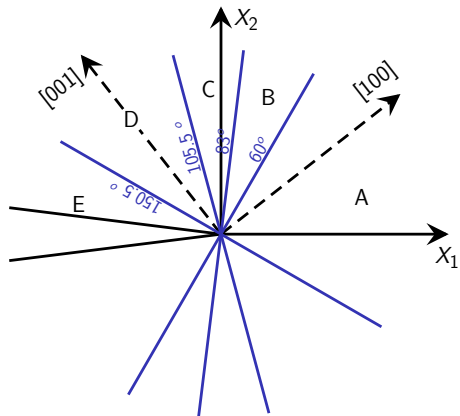
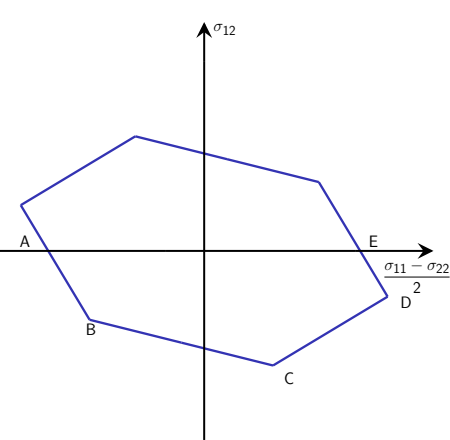
▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations



Extension to non-symmetrical crystal orientations

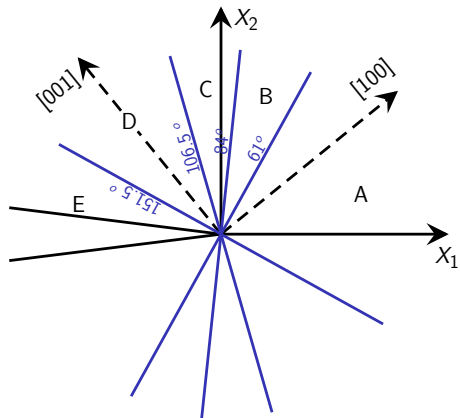
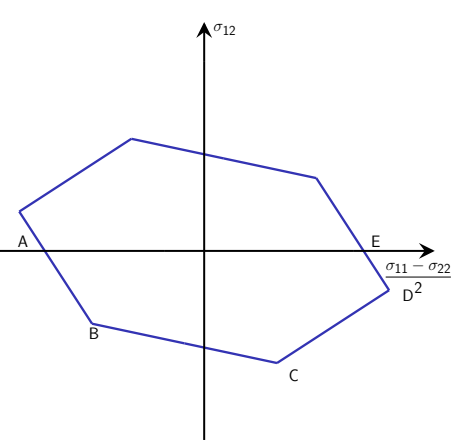


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

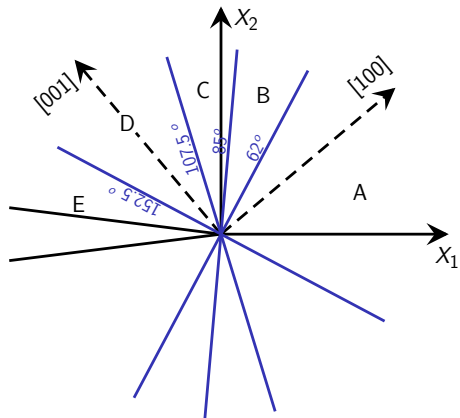
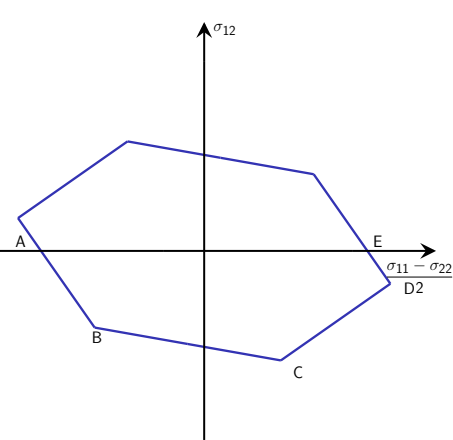


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

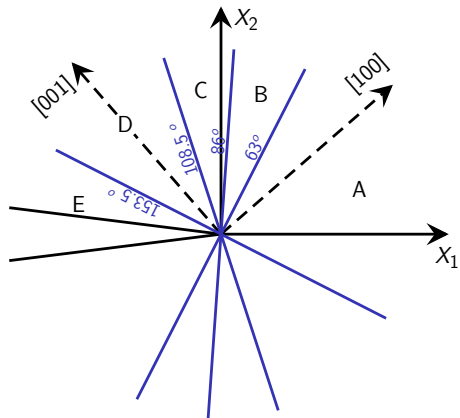
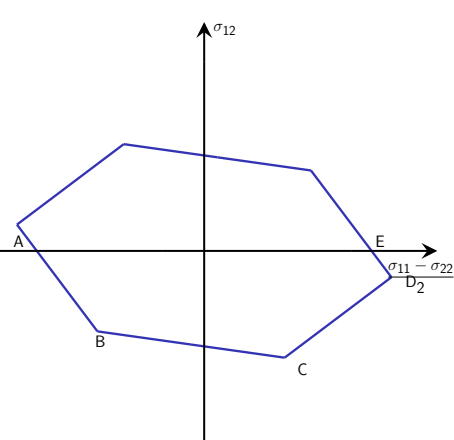


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

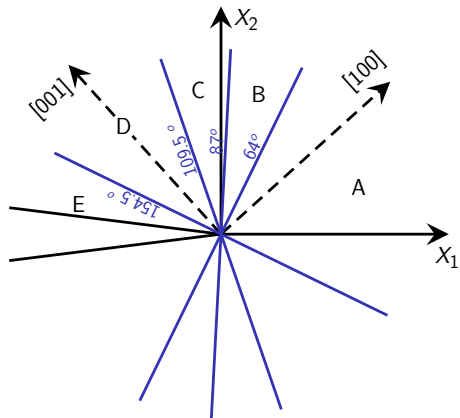
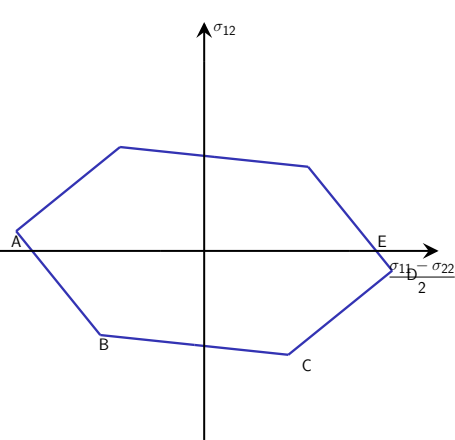


◀ Start

▶ Animation

▶▶ End

Extension to non-symmetrical crystal orientations

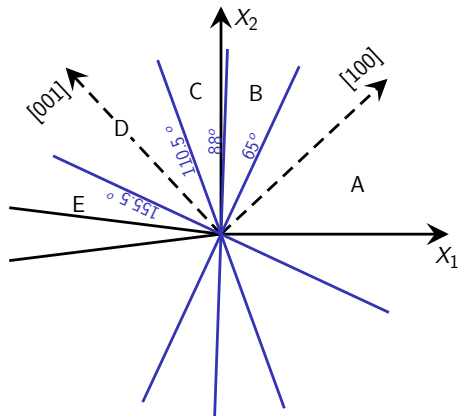
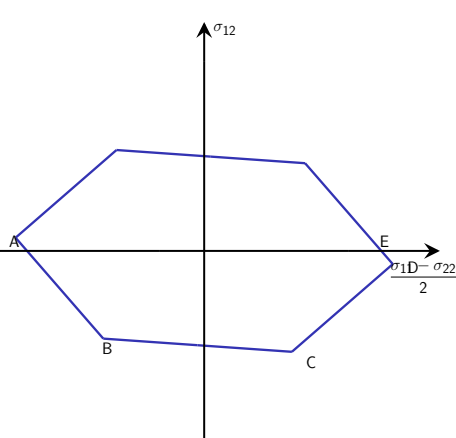


◀ Start

▶ Animation

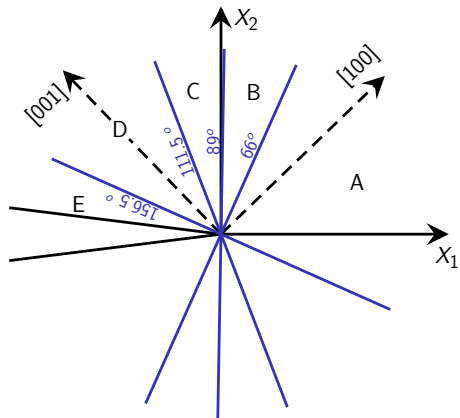
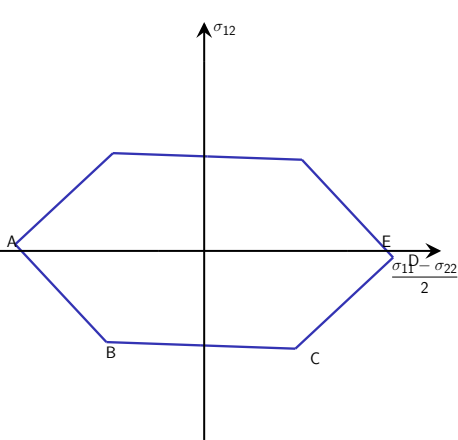
▶▶ End

Extension to non-symmetrical crystal orientations

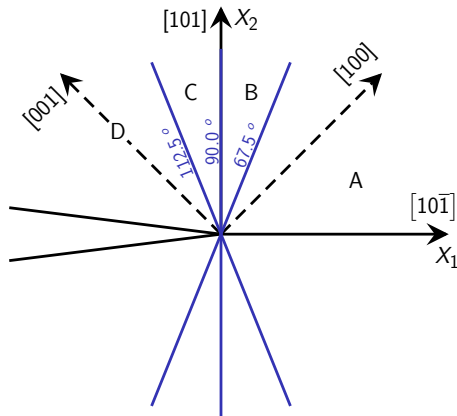
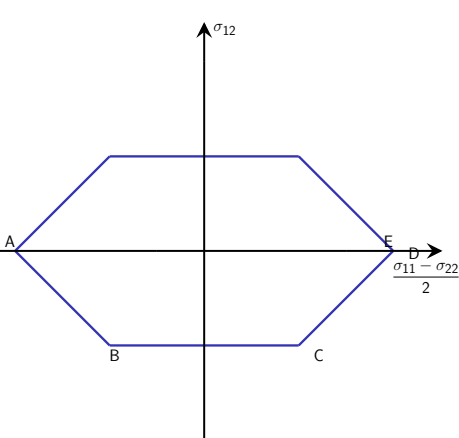


◀ Start ▶ Animation ▶▶ End

Extension to non-symmetrical crystal orientations



Extension to non-symmetrical crystal orientations



◀ Start

▶ Animation

▶▶ End

Experimental work

[Cho, 1991] [Li, 1991] [Shield, 1994, 1996] [Crone, 2001]

- Procedures :

- ① four-point bending test
- ② aluminium/copper
- ③ interferometry

- Observations :

- ① slip lines at the free surface
- ② sectors
- ③ displacement field measurement
- ④ strain field at the free surface
- ⑤ lattice orientation field at the free surface

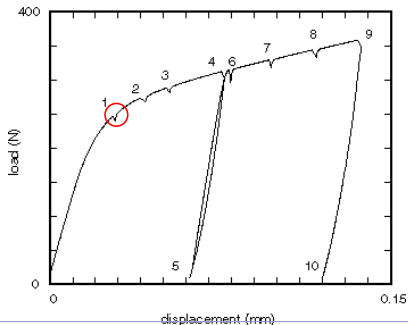
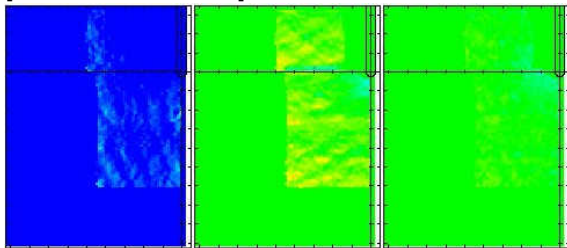
Experimental work

[Shield, 1994, 1996]

◀ Start

▶ Animation

▶▶ End



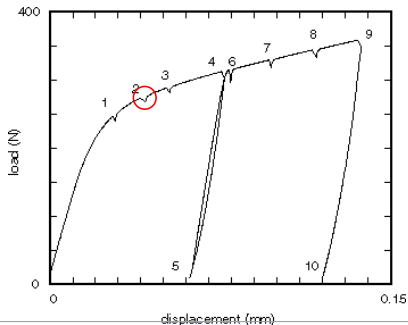
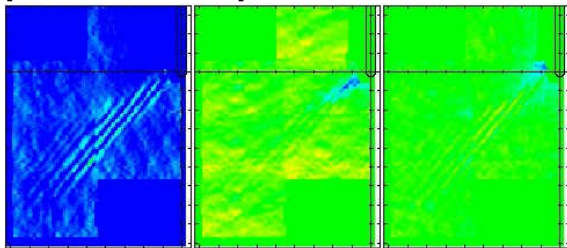
Experimental work

[Shield, 1994, 1996]

◀ Start

▶ Animation

▶▶ End



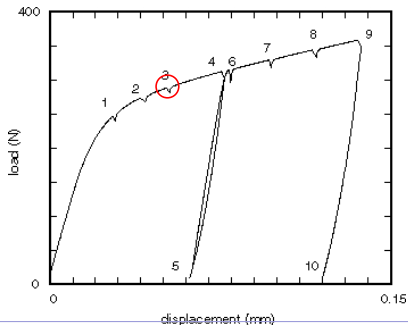
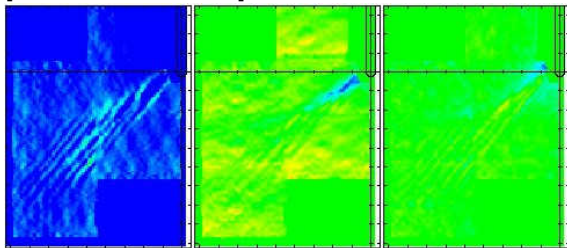
Experimental work

[Shield, 1994, 1996]

◀ Start

▶ Animation

▶▶ End



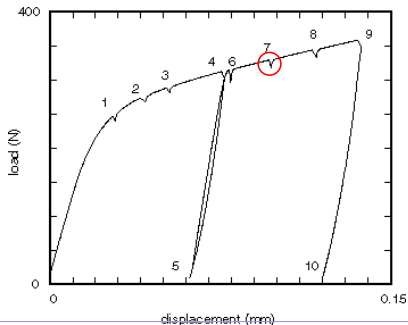
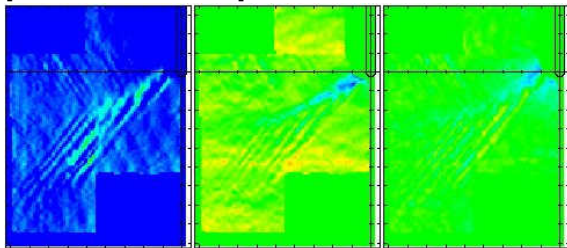
Experimental work

[Shield, 1994, 1996]

◀ Start

▶ Animation

▶▶ End



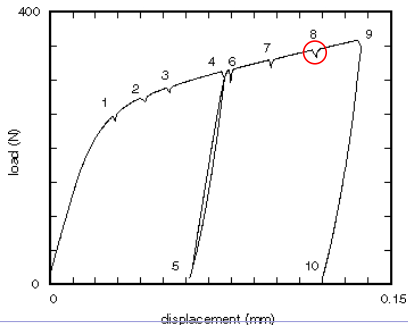
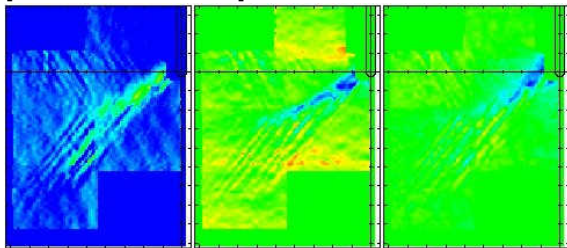
Experimental work

[Shield, 1994, 1996]

◀ Start

▶ Animation

▶▶ End



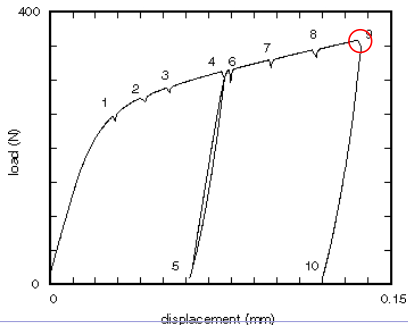
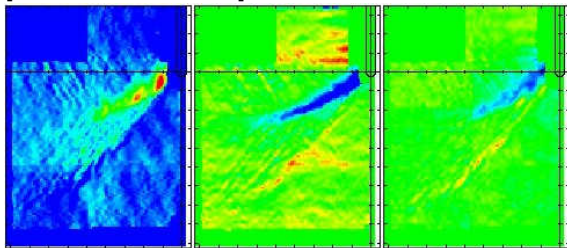
Experimental work

[Shield, 1994, 1996]

◀ Start

▶ Animation

▶▶ End



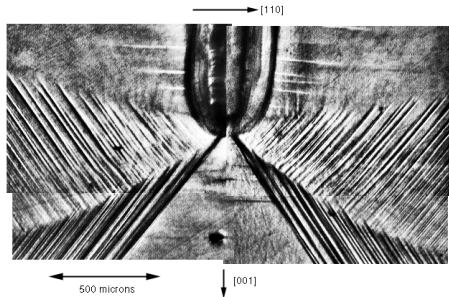
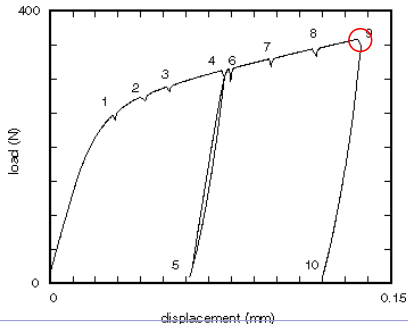
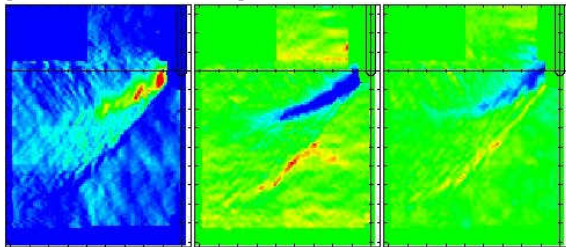
Experimental work

[Shield, 1994, 1996]

◀ Start

▶ Animation

▶▶ End



Limitations

Theory-hypotheses

- perfect plasticity
- confined plasticity
- plane strain
- crack

Experimental procedure

- copper and aluminium
→ work-hardening
- large plastic zone
- observation at the free surface
- notch

Solutions

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- **confined plasticity**
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- Ni-base SX superalloy

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Experimental procedure

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Solutions

- Ni-base SX superalloy
- CT specimen

Limitations

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Experimental procedure

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- notch

Solutions

- Ni-base SX superalloy
- CT specimen
- 3D computation

Limitations

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Experimental procedure

- copper and aluminium
→ work-hardening
- large plastic zone
- observation at the free surface
- notch

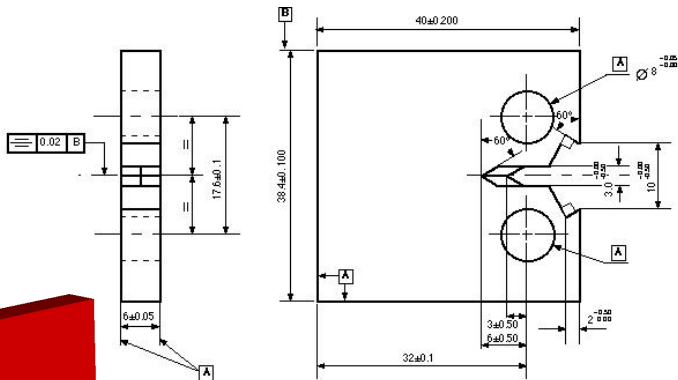
Solutions

- Ni-base SX superalloy
- CT specimen
- 3D computation
- pre-cracking

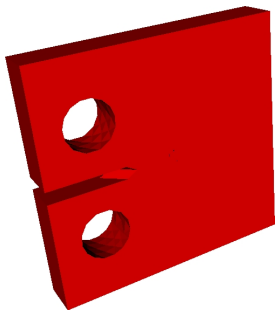
Plan

- 1 Introduction
- 2 Rice's solution of the crack problem in SX
 - Plane strain and effective slip systems
 - Balance of momentum; field equations
 - Extension of the solutions
- 3 3D effects on the crack tip fields
 - Loading conditions
 - Comparison surface-core
- 4 Confrontation to experimental results
- 5 Application to fatigue
 - Deformation at the crack tip under cyclic loading
 - Crack propagation paths
- 6 Conclusions-perspectives

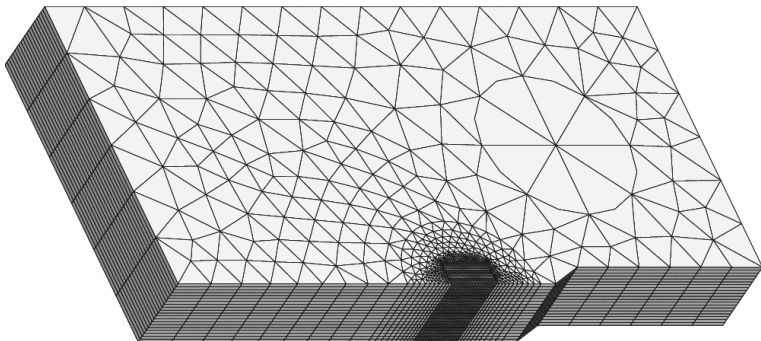
Conditions for the computation



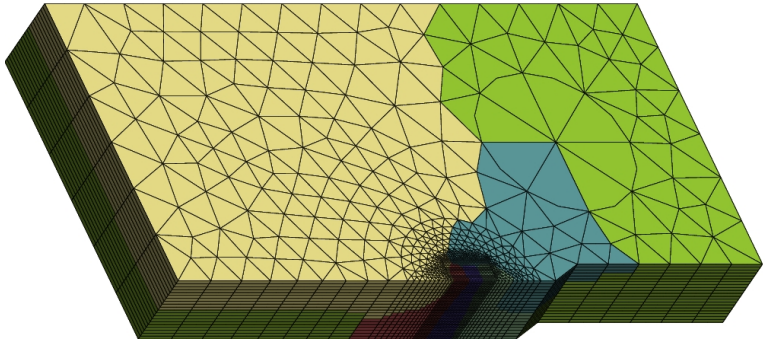
CT16 specimen



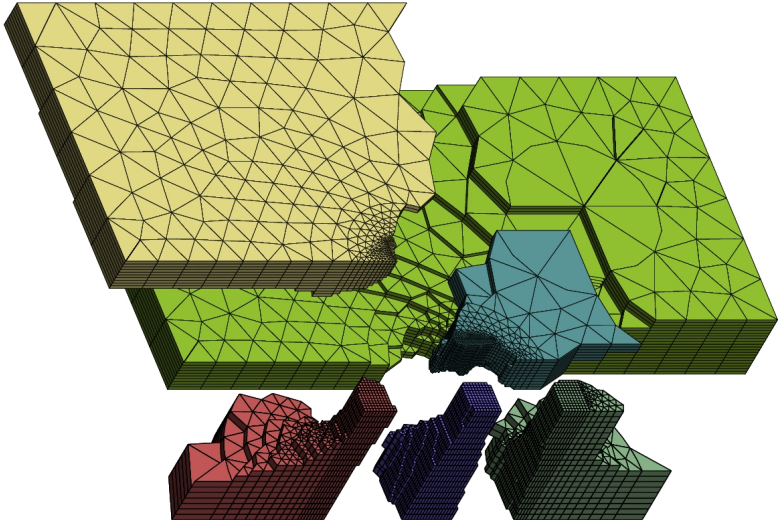
Conditions for the computation



Conditions for the computation



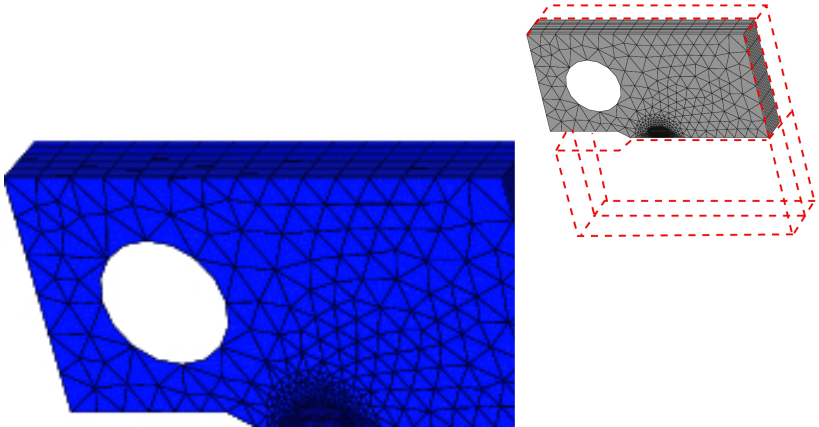
Conditions for the computation



Plan

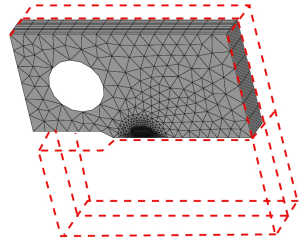
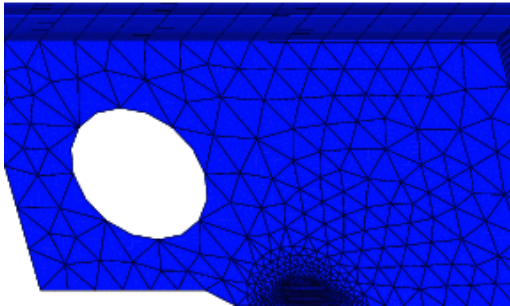
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3D analyses - Orientation S γ (001)[110]



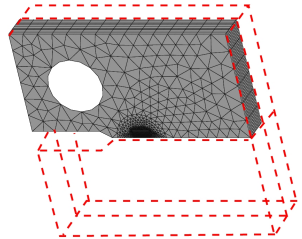
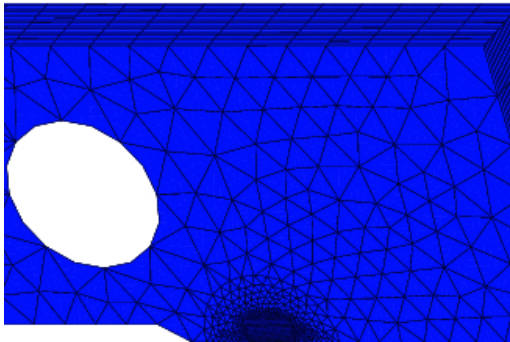
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3D analyses - Orientation $S \sim (001)[110]$



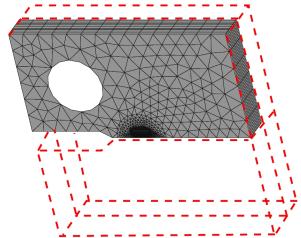
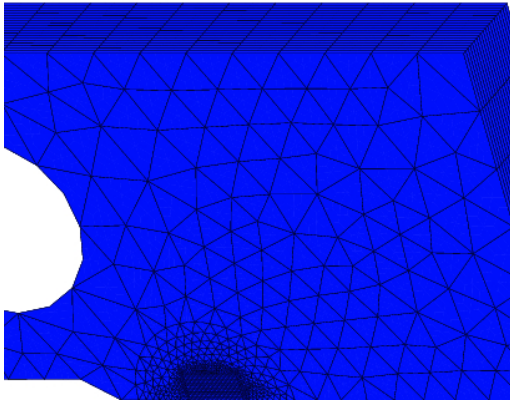
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3D analyses - Orientation $S \sim (001)[110]$



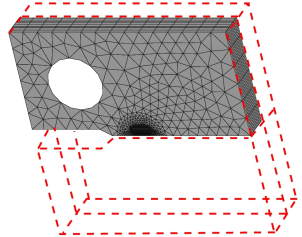
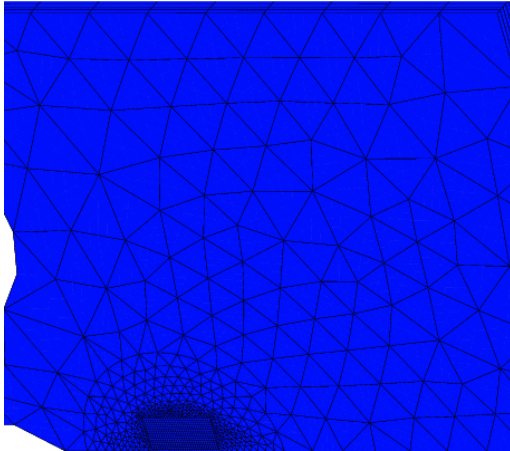
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3D analyses - Orientation S γ (001)[110]



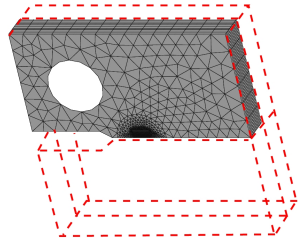
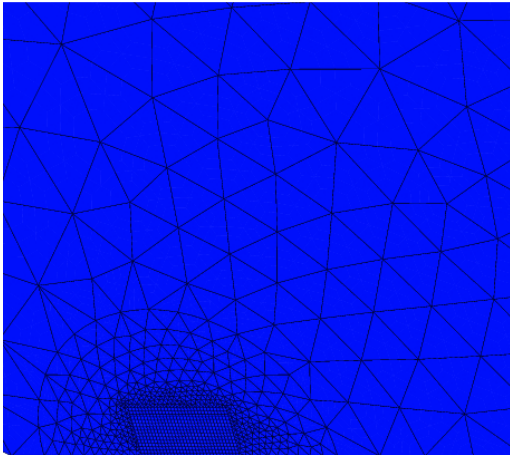
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3D analyses - Orientation S γ (001)[110]



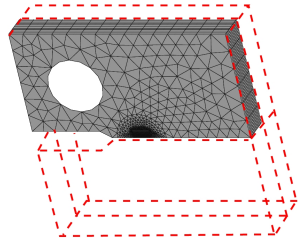
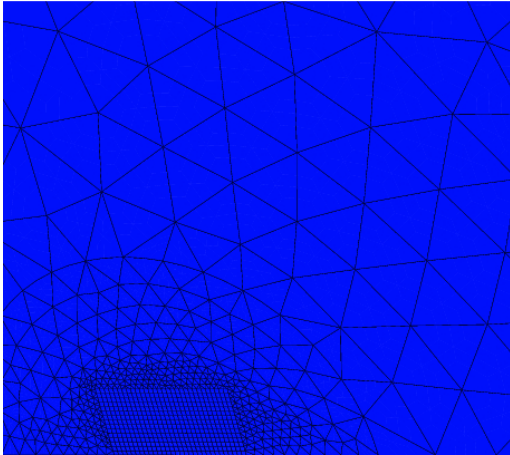
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3D analyses - Orientation $S \sim (001)[110]$



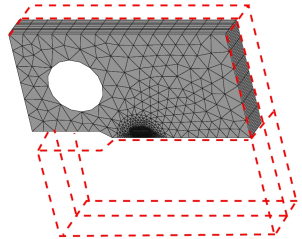
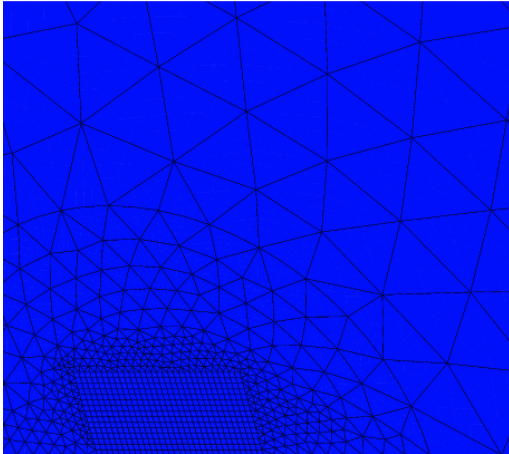
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3D analyses - Orientation S γ (001)[110]



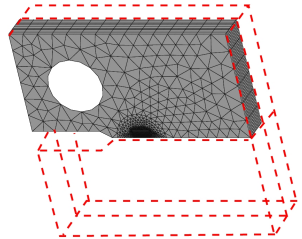
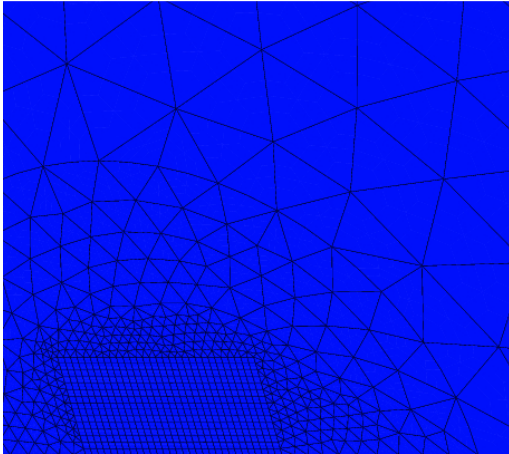
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3D analyses - Orientation S γ (001)[110]



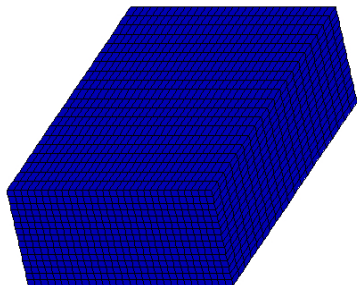
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3D analyses - Orientation S γ (001)[110]

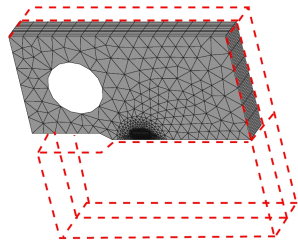


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3D analyses - Orientation S γ (001)[110]

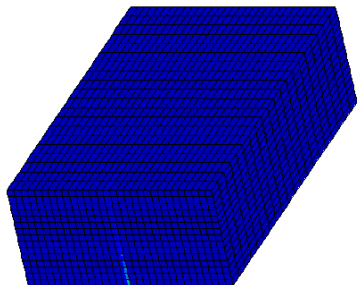


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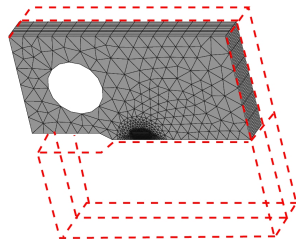


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3D analyses - Orientation S γ (001)[110]

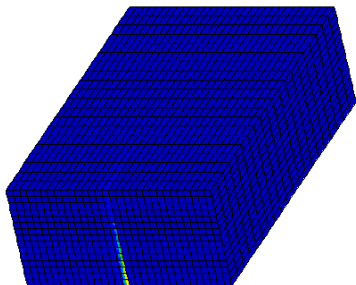


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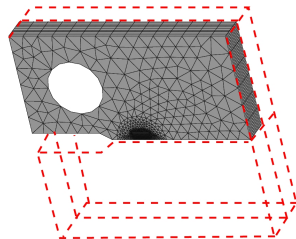


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3D analyses - Orientation S γ (001)[110]

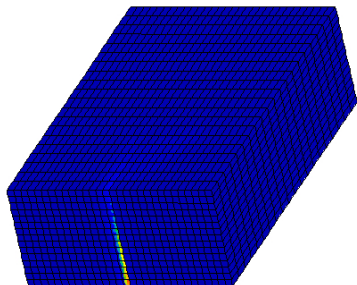


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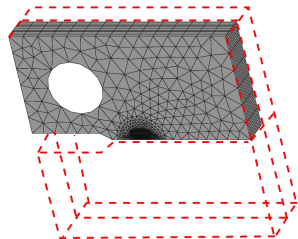


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3D analyses - Orientation S γ (001)[110]

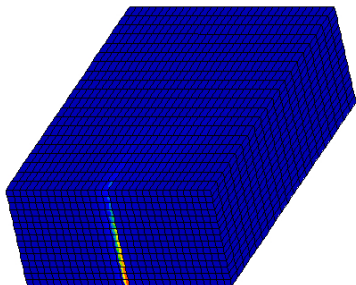


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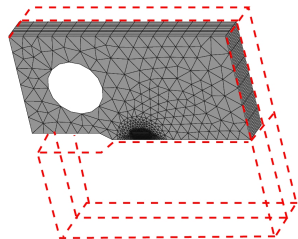


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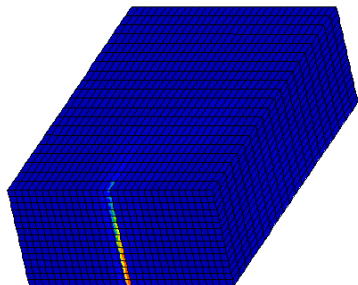


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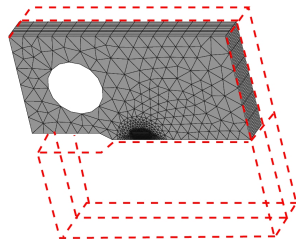


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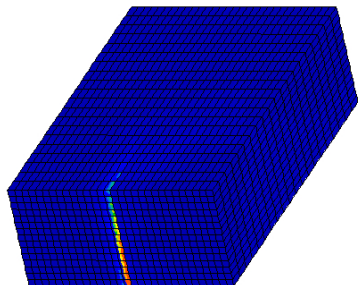


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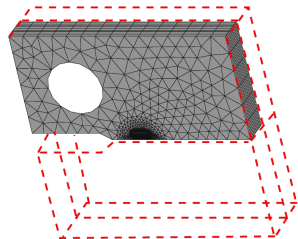


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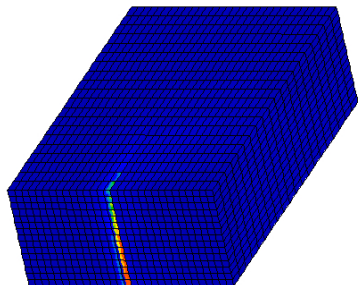


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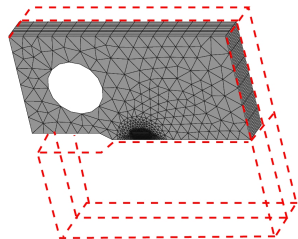


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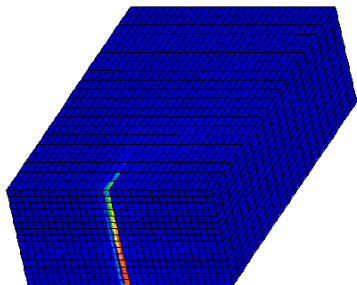


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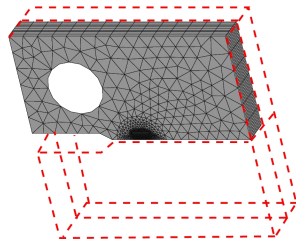


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3D analyses - Orientation $S \sim (001)[110]$

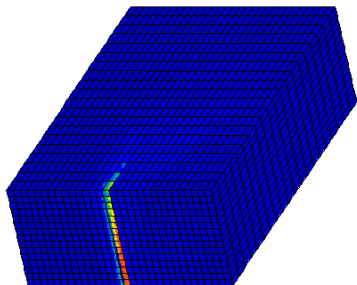


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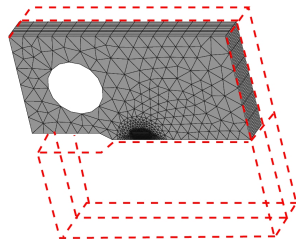


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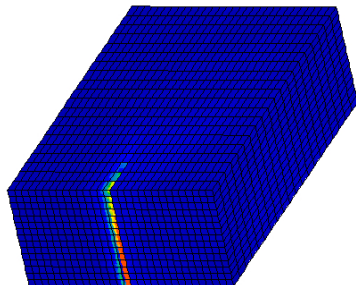


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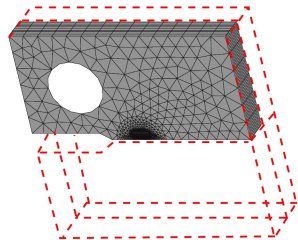


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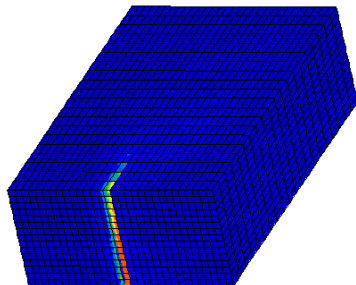


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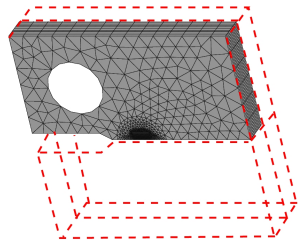


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$

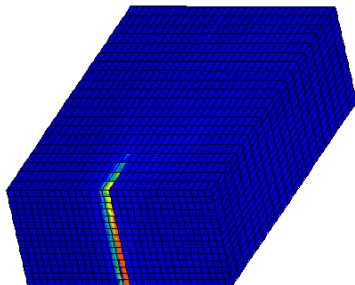


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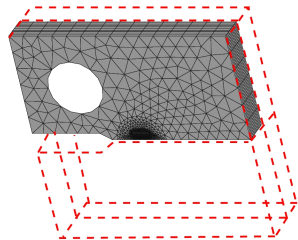


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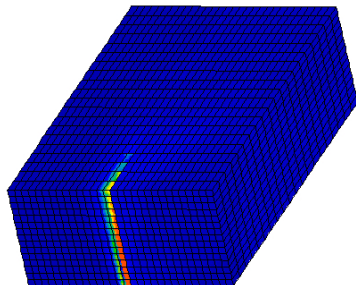


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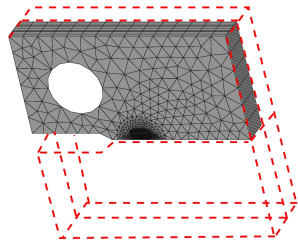


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3D analyses - Orientation $S \sim (001)[110]$

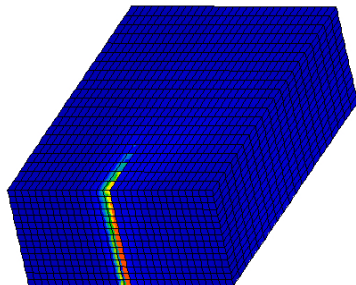


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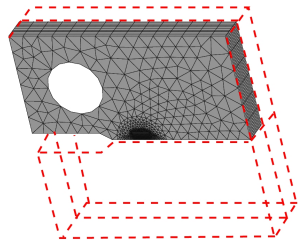


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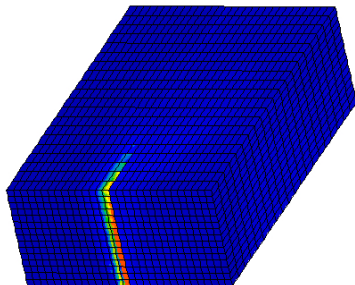


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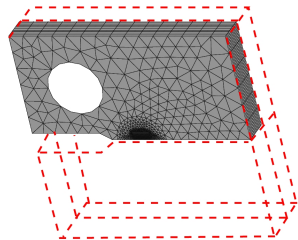


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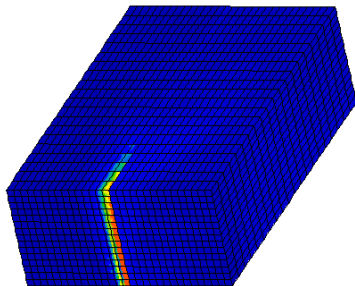


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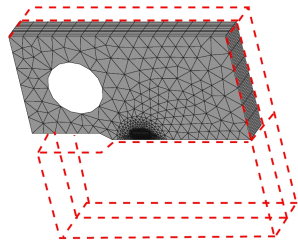


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation S γ (001)[110]

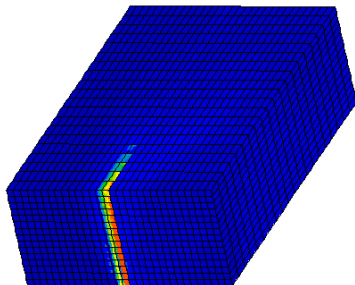


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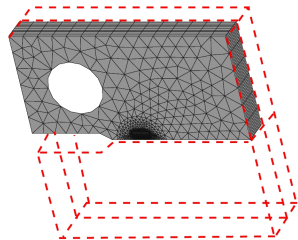


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$

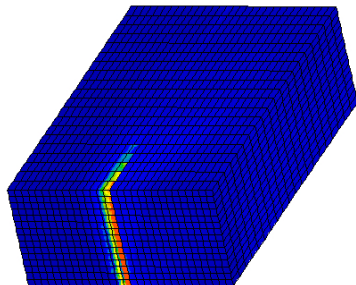


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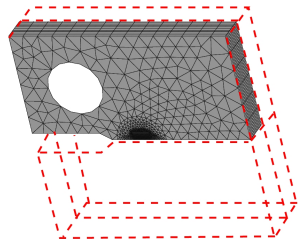


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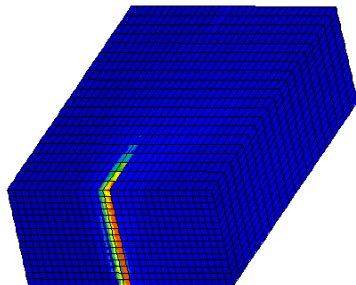


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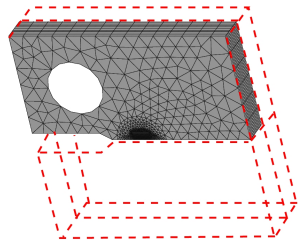


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation S γ (001)[110]

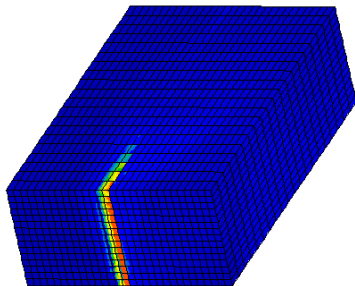


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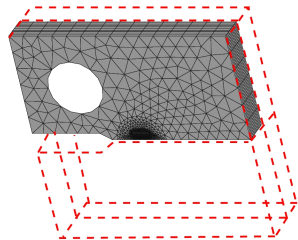


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation S γ (001)[110]

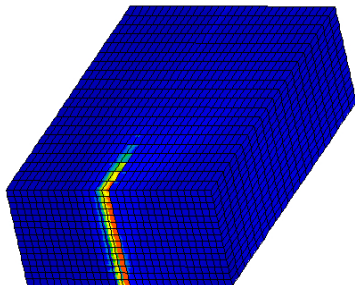


1.5mm

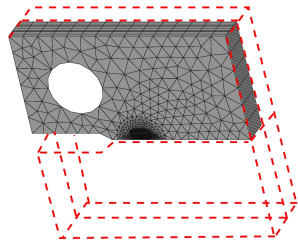


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation S γ (001)[110]

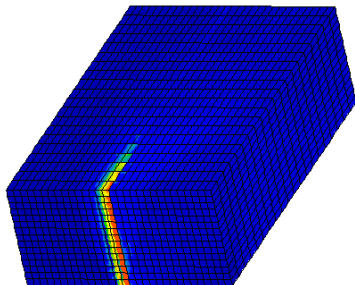


1.5mm

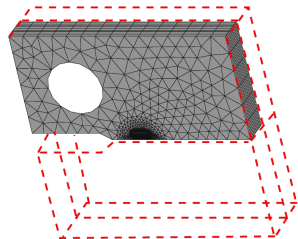


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation S γ (001)[110]

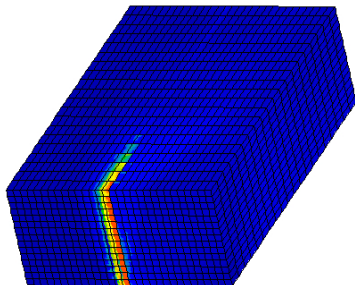


1.5mm



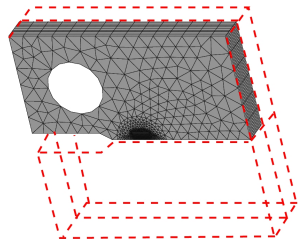
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$

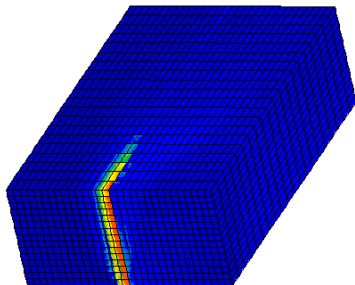


1.5mm

◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

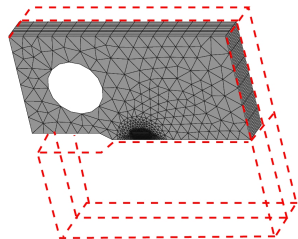


3D analyses - Orientation S γ (001)[110]

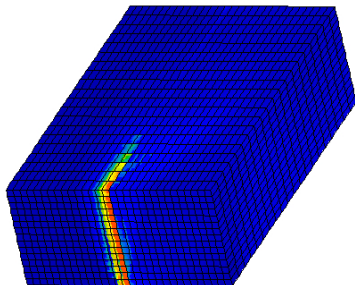


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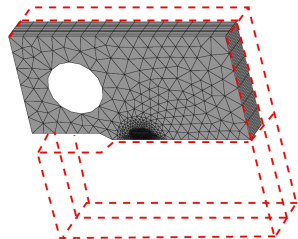
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End



3D analyses - Orientation S γ (001)[110]

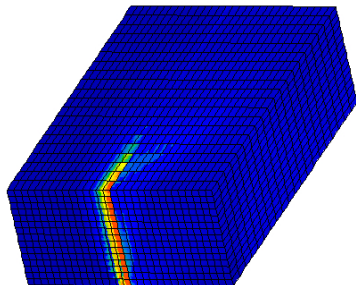


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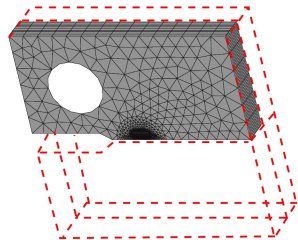


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation S γ (001)[110]

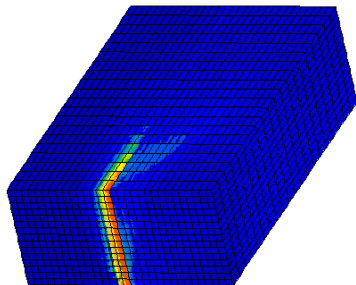


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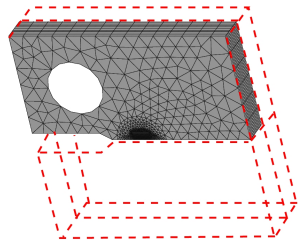


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$

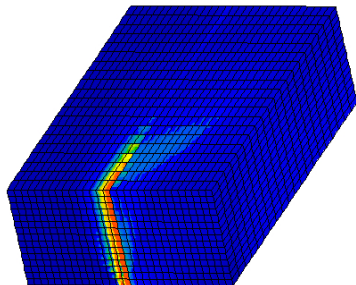


1.5mm

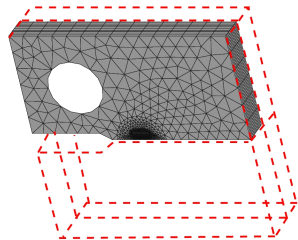


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$

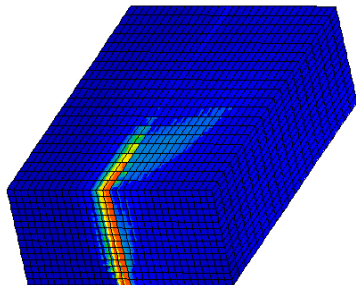


1.5mm



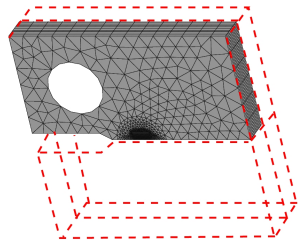
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$

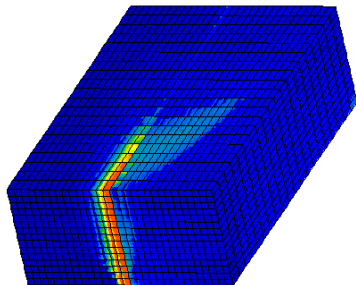


1.5mm

◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

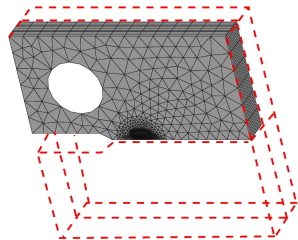


3D analyses - Orientation $S \sim (001)[110]$

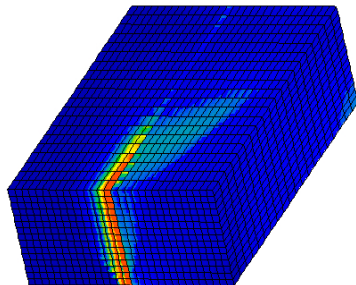


1.5mm

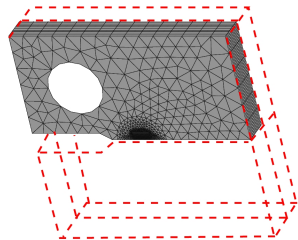
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End



3D analyses - Orientation $S \sim (001)[110]$

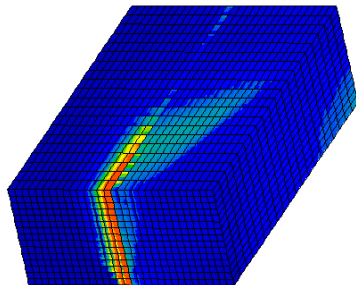


1.5mm

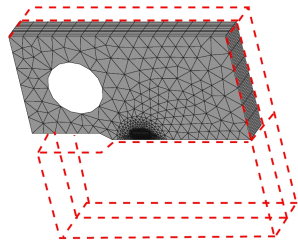


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$

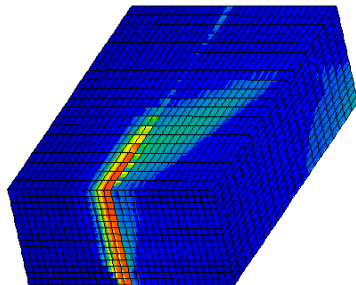


1.5mm

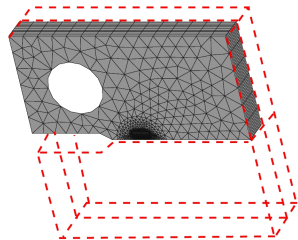


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$

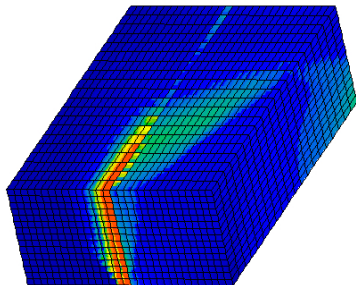


1.5mm

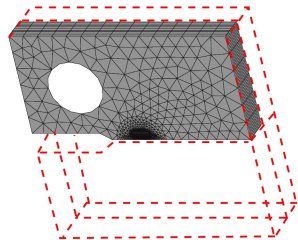


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$

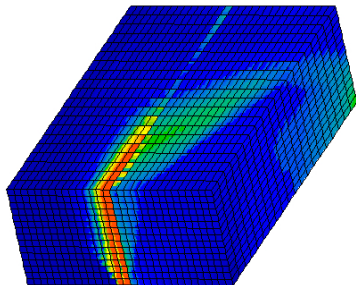


1.5mm

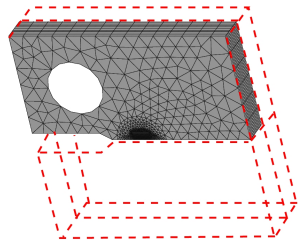


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$

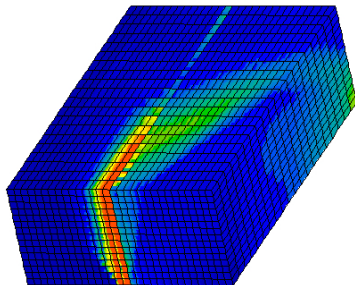


1.5mm



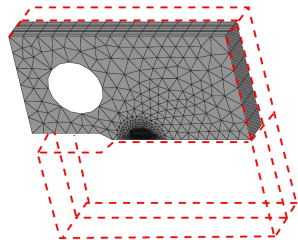
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$

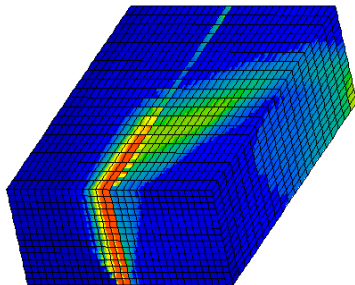


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◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

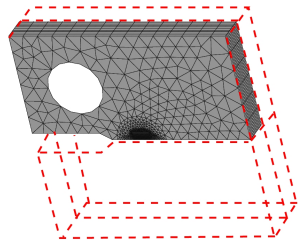


3D analyses - Orientation $S \sim (001)[110]$

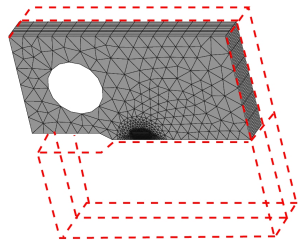
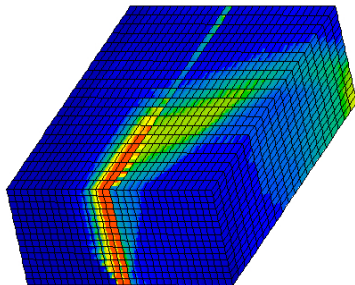


1.5mm

◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

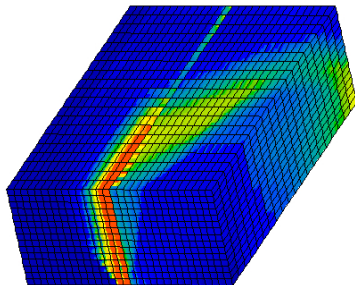


3D analyses - Orientation $S \sim (001)[110]$

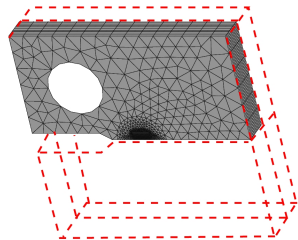


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$

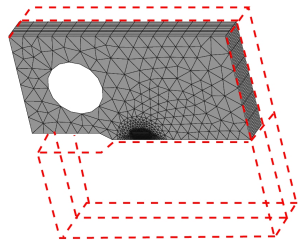
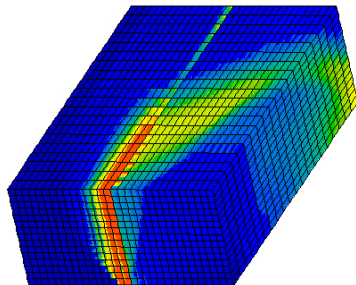


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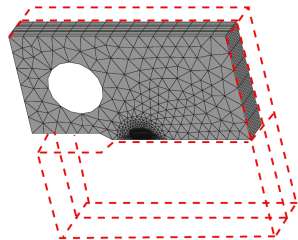
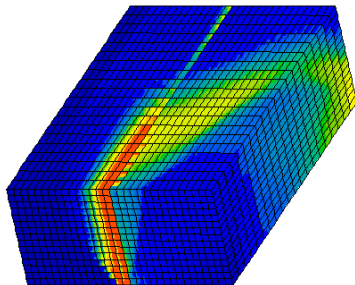
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$



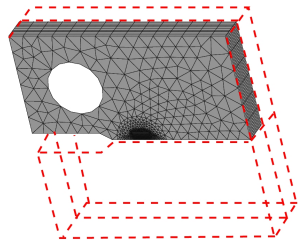
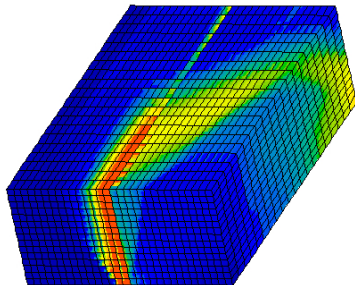
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$



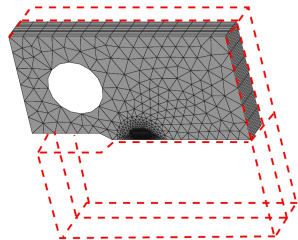
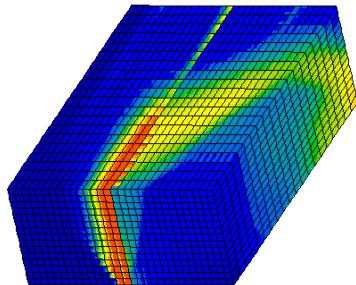
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$



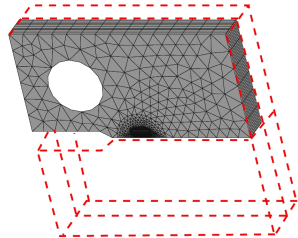
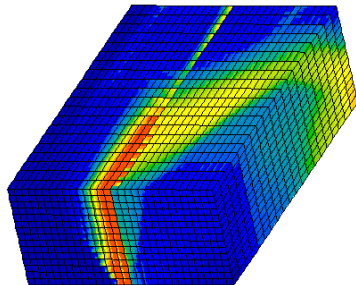
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$



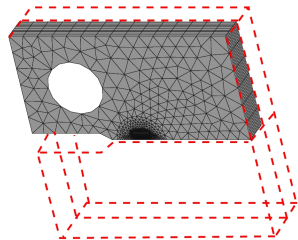
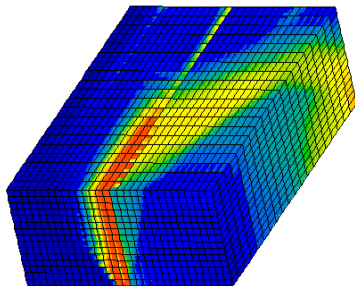
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$



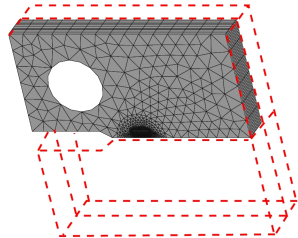
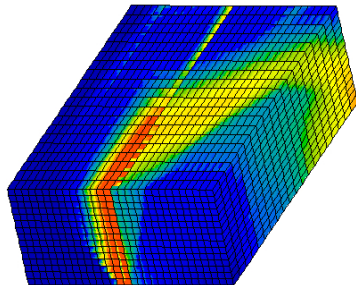
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation S γ (001)[110]



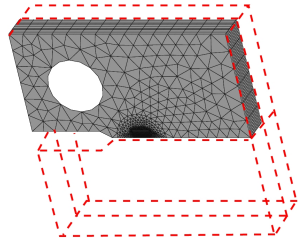
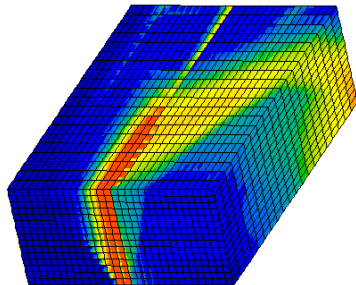
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$



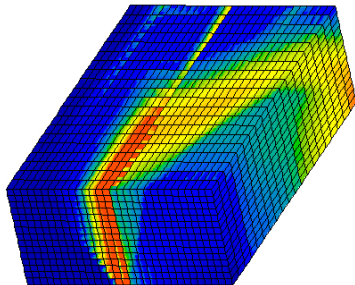
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$

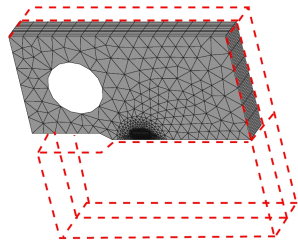


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$

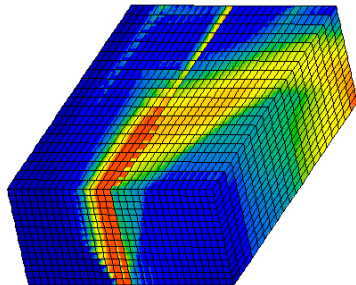


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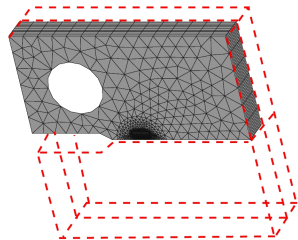


◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$

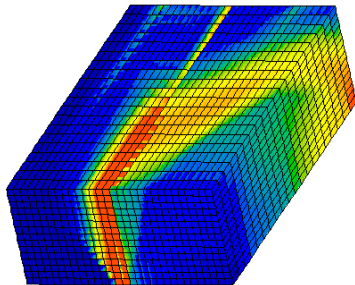


1.5mm



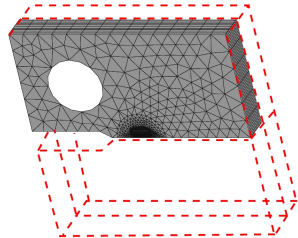
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$

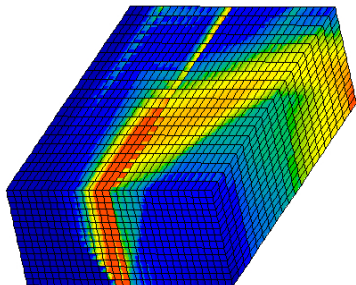


1.5mm

◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

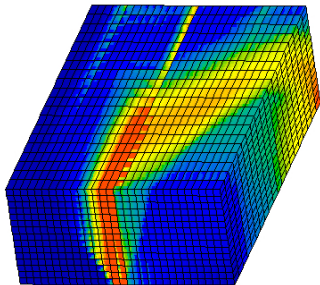


3D analyses - Orientation $S \gamma (001)[110]$



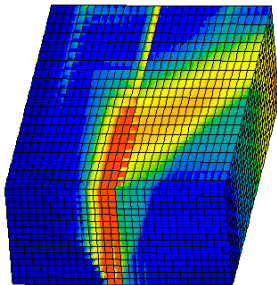
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$



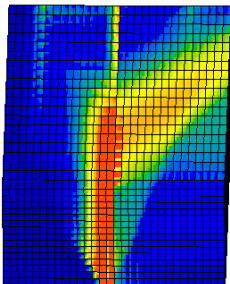
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$



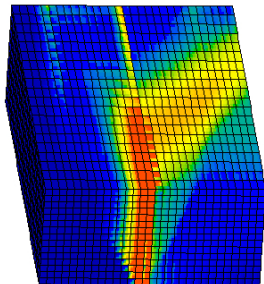
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \gamma (001)[110]$



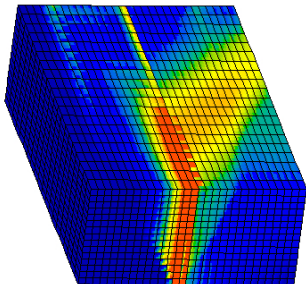
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$



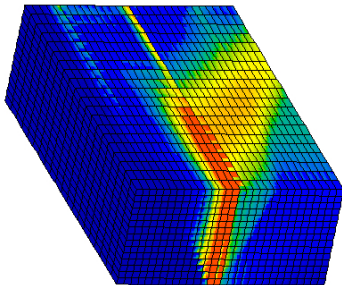
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$



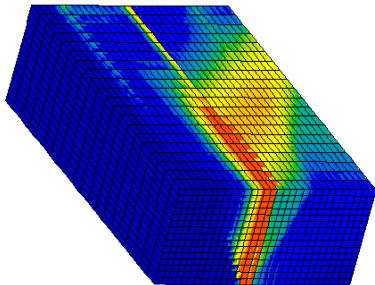
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$



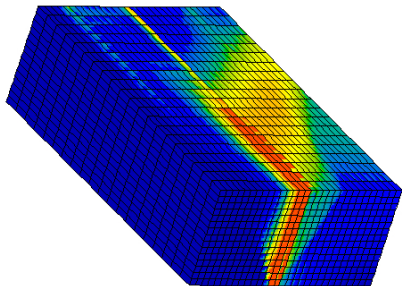
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$



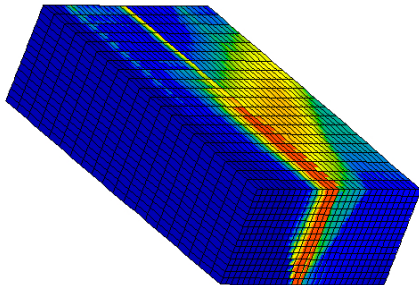
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$



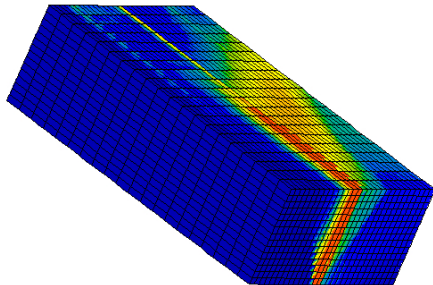
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$



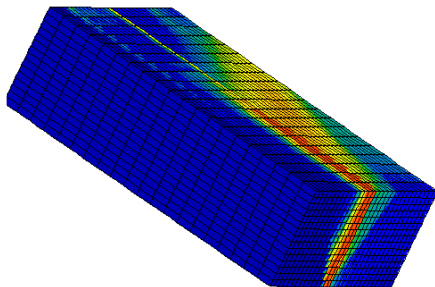
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$



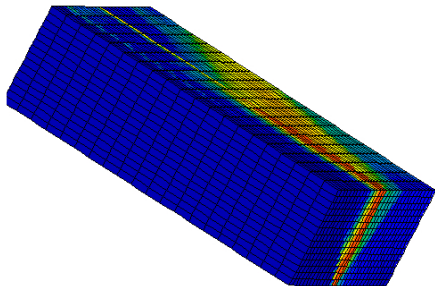
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$



◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$



◀ Start

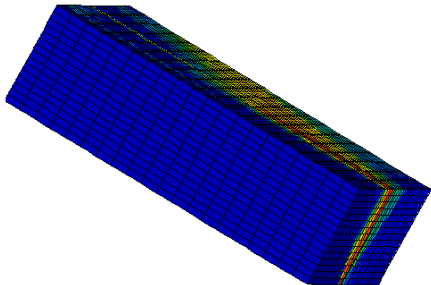
▶ Zoom

▶ Tension

▶ Rotation

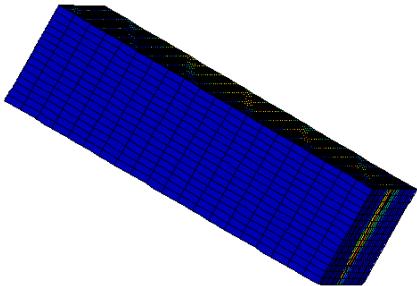
▶ End

3D analyses - Orientation $S \sim (001)[110]$



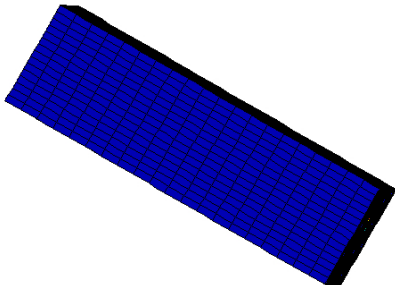
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$



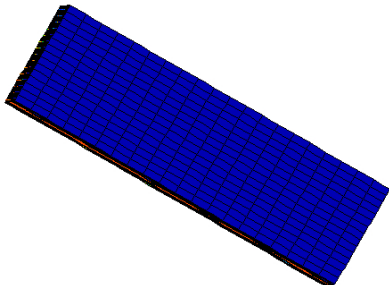
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation S γ (001)[110]



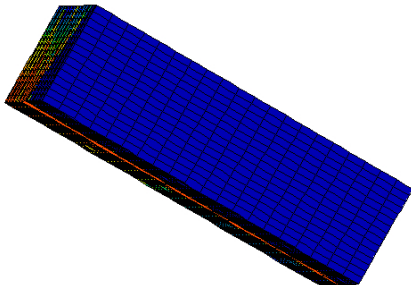
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$



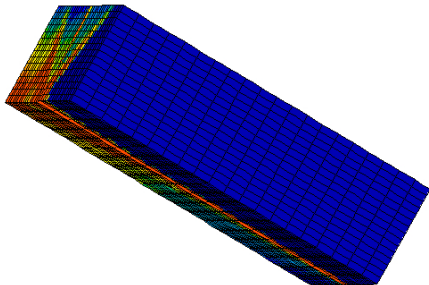
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$



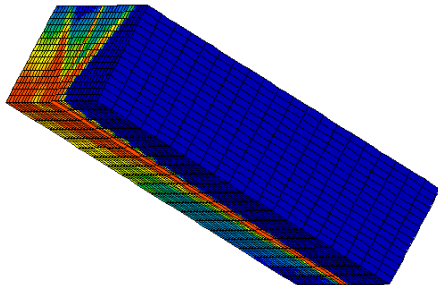
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$



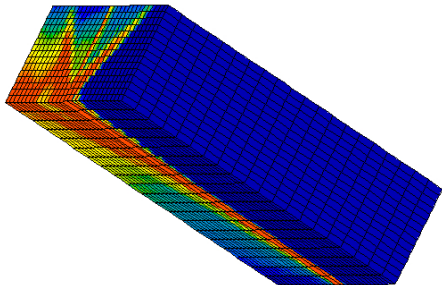
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \sim (001)[110]$



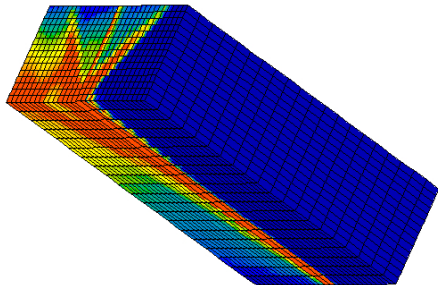
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$



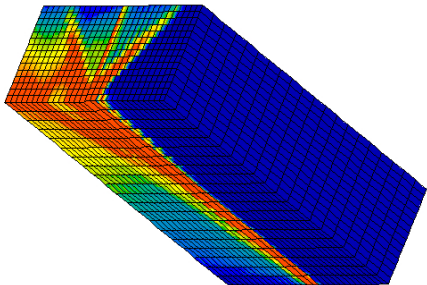
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \gamma (001)[110]$



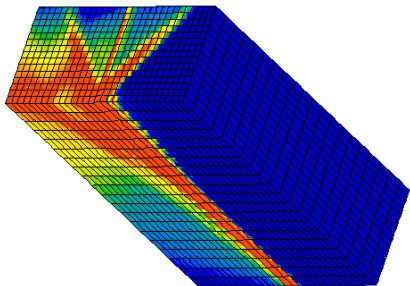
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \gamma (001)[110]$



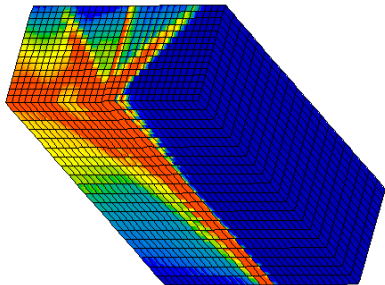
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$



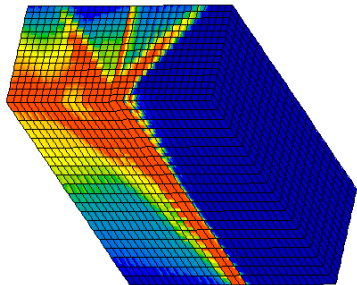
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $S \rightarrow (001)[110]$



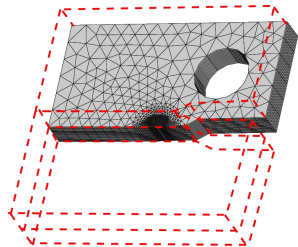
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation S γ (001)[110]

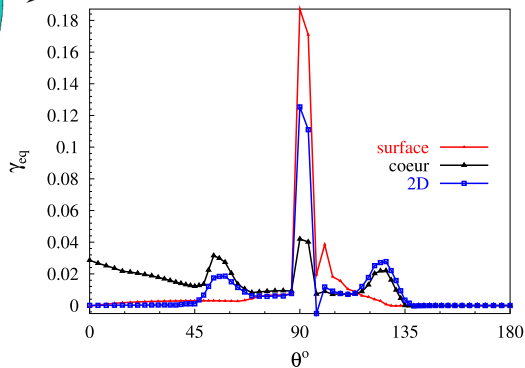
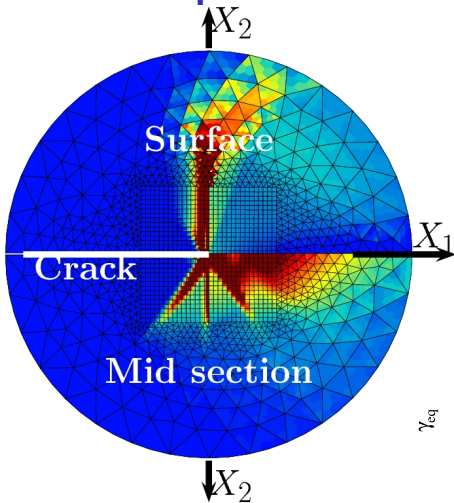


1.5mm

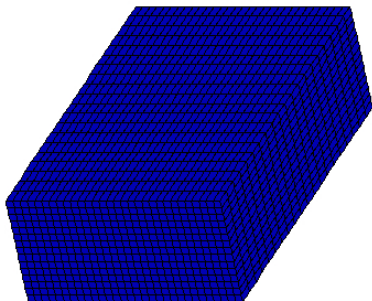
◀ Start ▶ Zoom ▶ Tension ▶ Rotation ▶ End



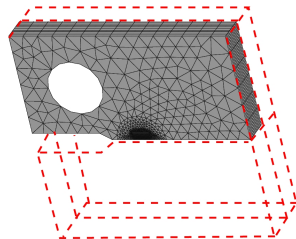
Comparason surface-core - Orientation S



3D analyses - Orientation $K \propto (110)[001]$

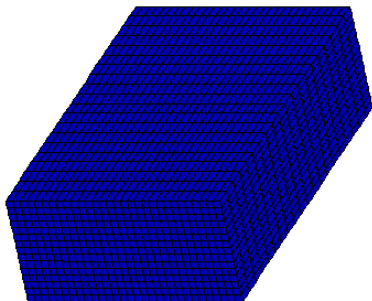


1.5mm

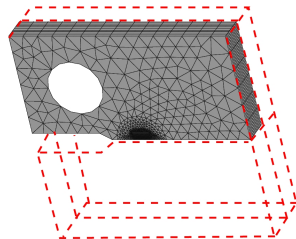


◀ Start ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $K \propto (110)[001]$

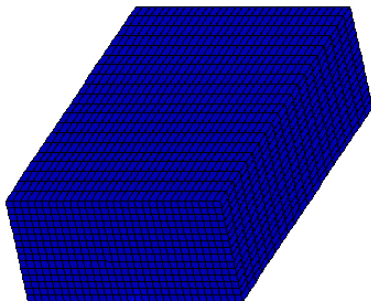


1.5mm

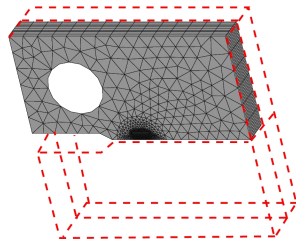


◀ Start ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $K \propto (110)[001]$

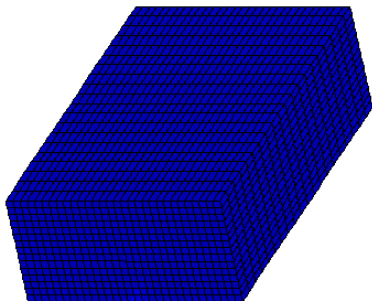


1.5mm

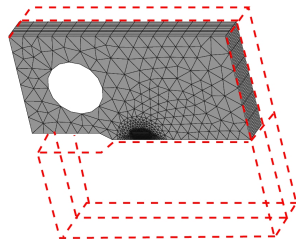


◀ Start ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $K \propto (110)[001]$

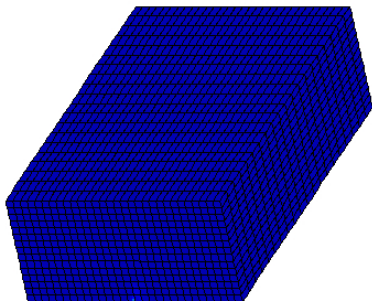


1.5mm

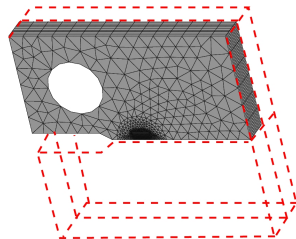


◀ Start ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $K \sim (110)[001]$

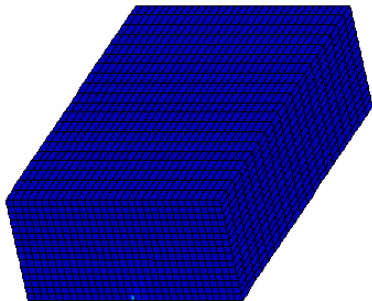


1.5mm

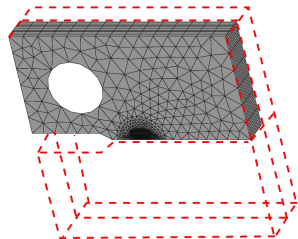


◀ Start ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $K \propto (110)[001]$

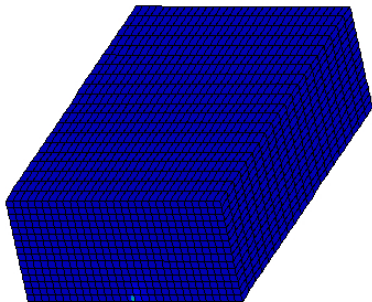


1.5mm

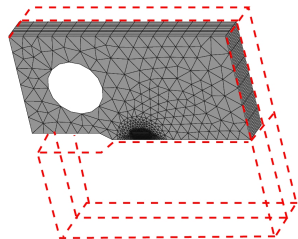


◀ Start ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $K \propto (110)[001]$

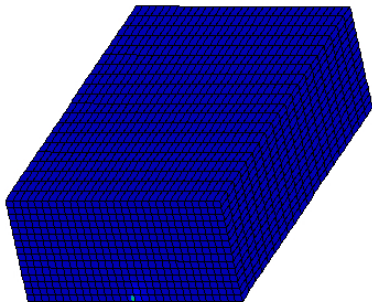


1.5mm

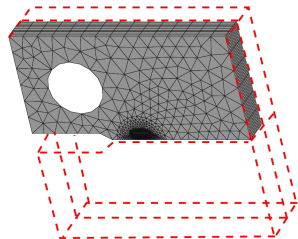


◀ Start ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $K \sim (110)[001]$

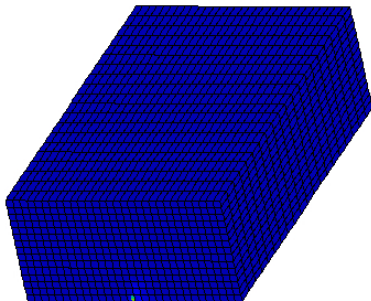


1.5mm



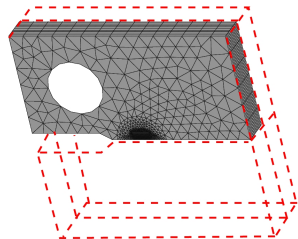
◀ Start ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $K \propto (110)[001]$

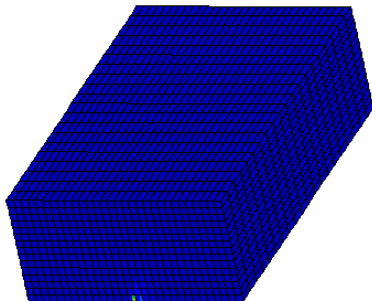


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

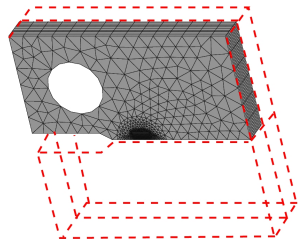


3D analyses - Orientation $K \propto (110)[001]$

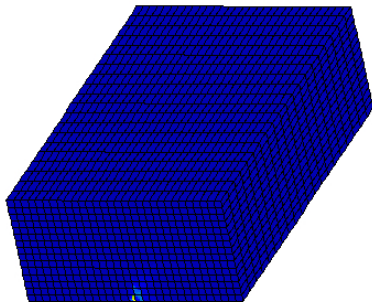


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

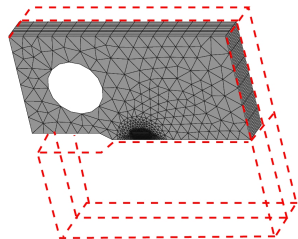


3D analyses - Orientation $K \sim (110)[001]$

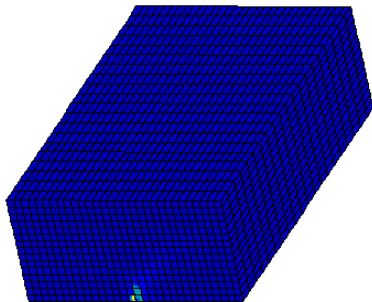


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

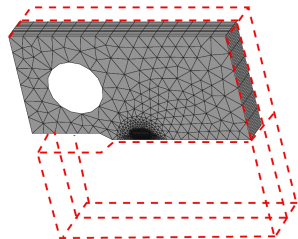


3D analyses - Orientation $K \sim (110)[001]$

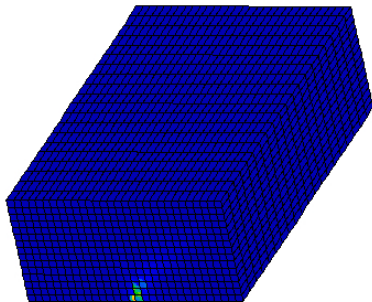


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

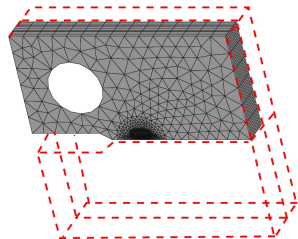


3D analyses - Orientation $K \propto (110)[001]$

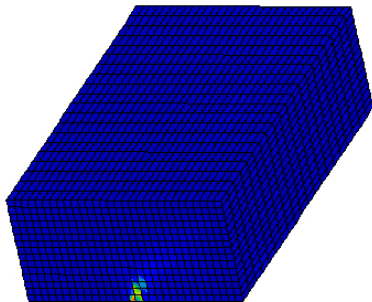


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

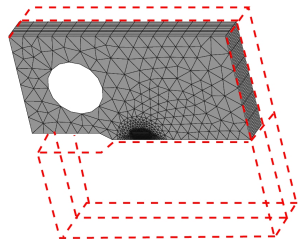


3D analyses - Orientation $K \sim (110)[001]$

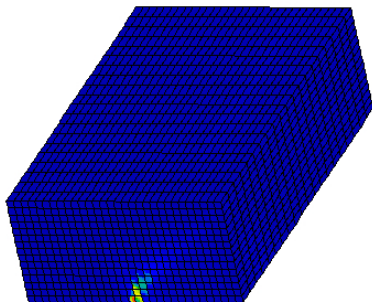


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

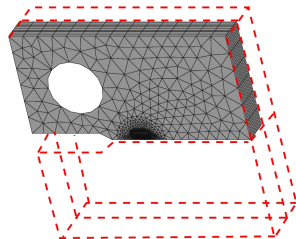


3D analyses - Orientation $K \sim (110)[001]$

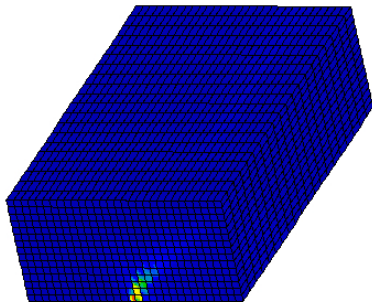


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

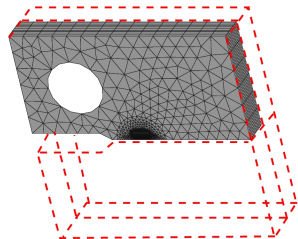


3D analyses - Orientation K $\gamma(110)[001]$

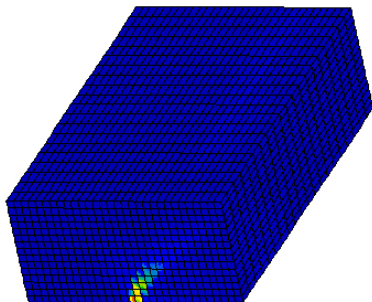


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

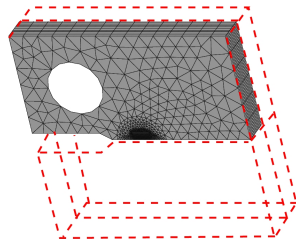


3D analyses - Orientation K $\gamma(110)[001]$

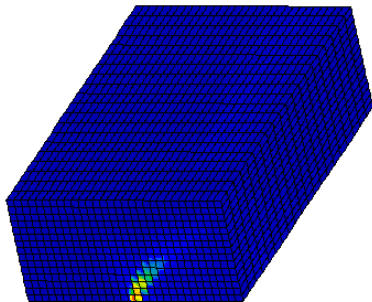


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

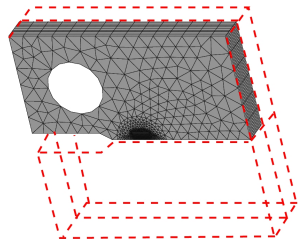


3D analyses - Orientation $K \propto (110)[001]$

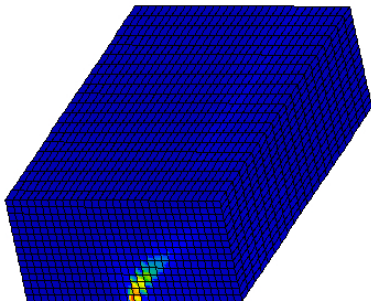


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

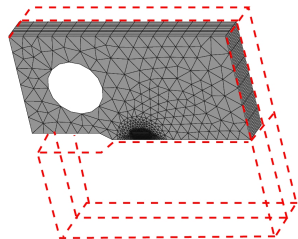


3D analyses - Orientation $K \sim (110)[001]$

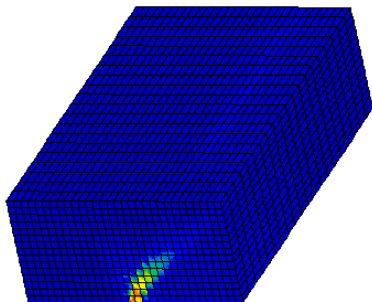


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

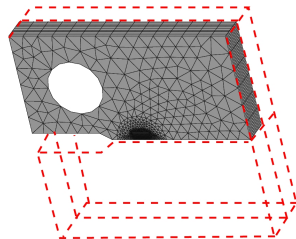


3D analyses - Orientation K $\gamma(110)[001]$

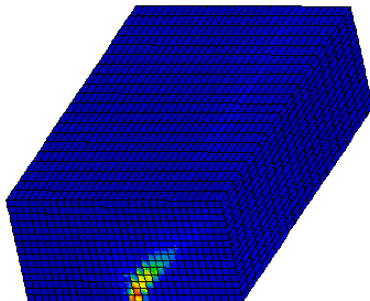


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

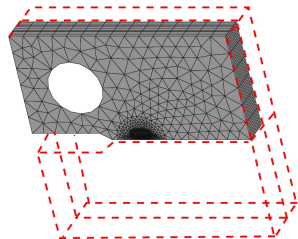


3D analyses - Orientation $K \propto (110)[001]$

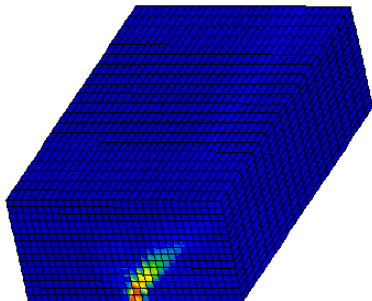


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

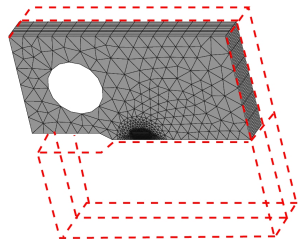


3D analyses - Orientation $K \propto (110)[001]$

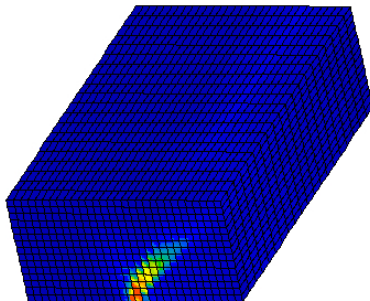


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

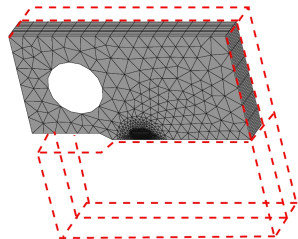


3D analyses - Orientation $K \sim (110)[001]$

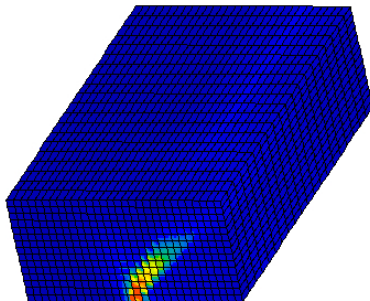


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

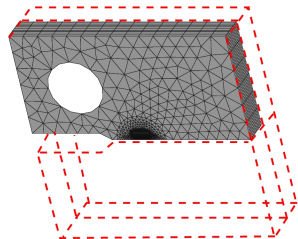


3D analyses - Orientation $K \sim (110)[001]$

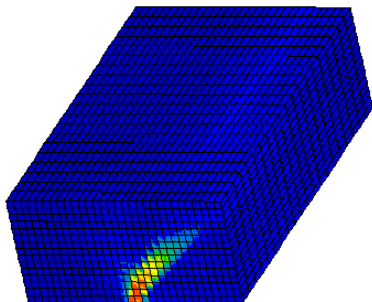


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

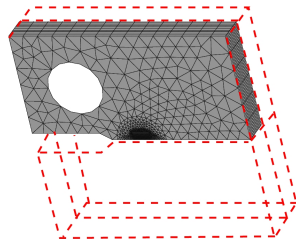


3D analyses - Orientation $K \sim (110)[001]$

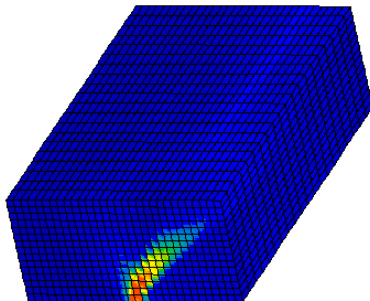


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

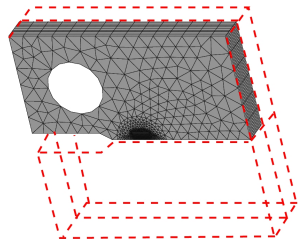


3D analyses - Orientation $K \propto (110)[001]$

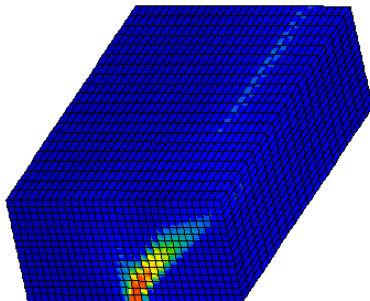


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

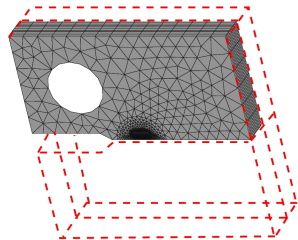


3D analyses - Orientation $K \sim (110)[001]$

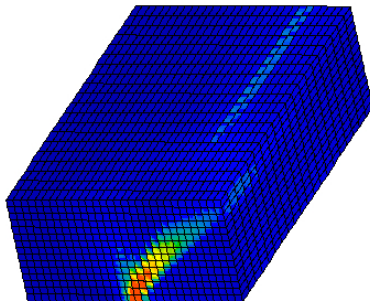


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

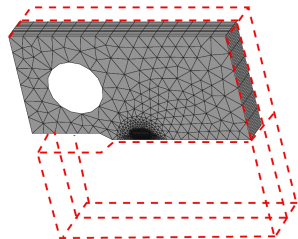


3D analyses - Orientation $K \propto (110)[001]$

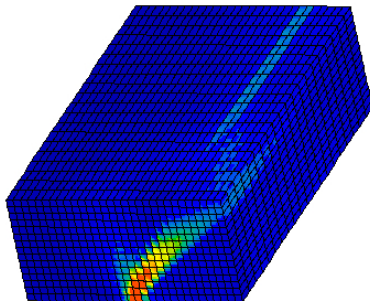


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

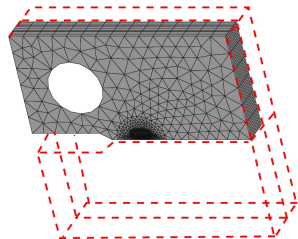


3D analyses - Orientation $K \sim (110)[001]$

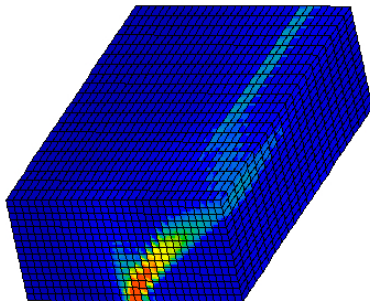


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

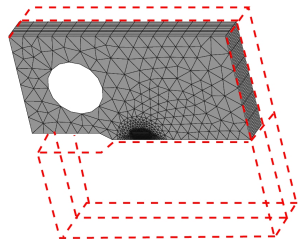


3D analyses - Orientation $K_{\gamma}(110)[001]$

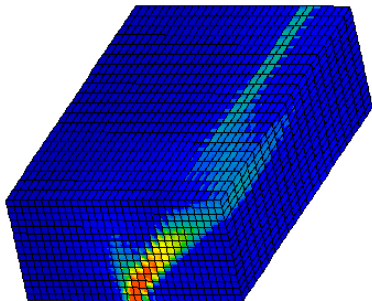


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

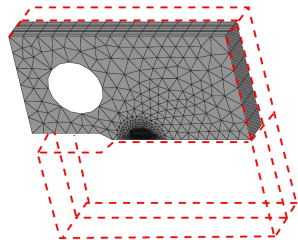


3D analyses - Orientation $K \propto (110)[001]$

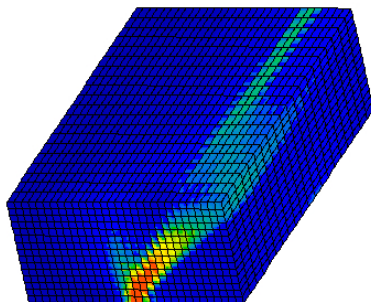


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

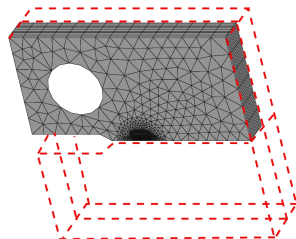


3D analyses - Orientation $K \propto (110)[001]$

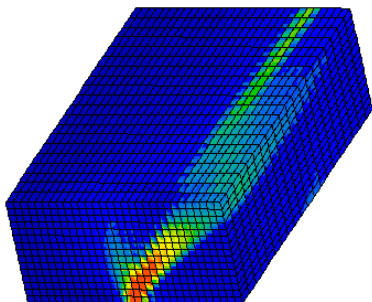


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

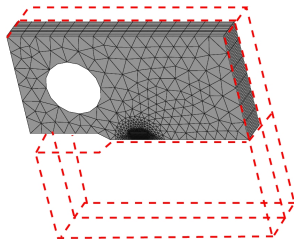


3D analyses - Orientation $K \propto (110)[001]$

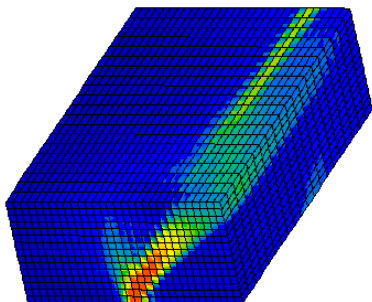


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

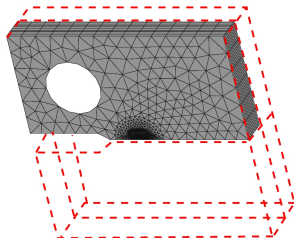


3D analyses - Orientation $K \propto (110)[001]$

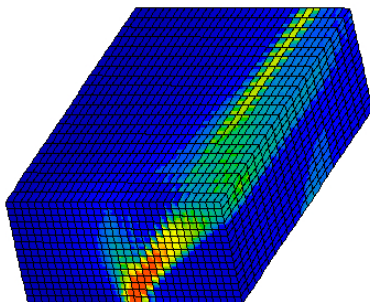


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

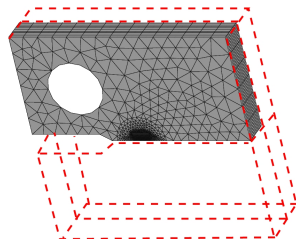


3D analyses - Orientation $K \propto (110)[001]$

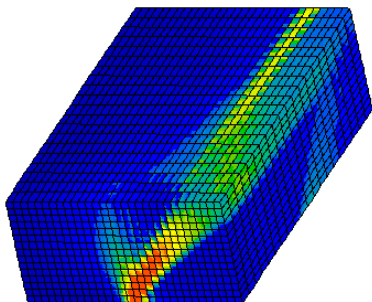


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

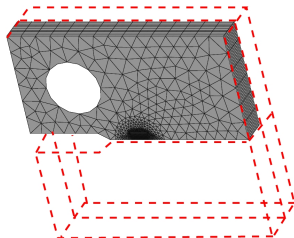


3D analyses - Orientation $K \propto (110)[001]$

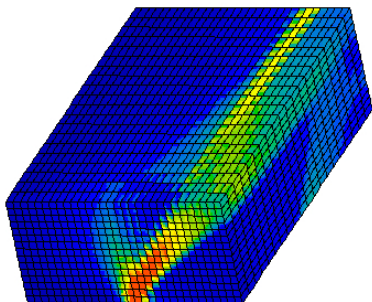


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

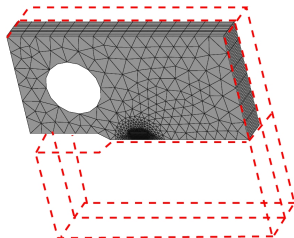


3D analyses - Orientation $K \propto (110)[001]$

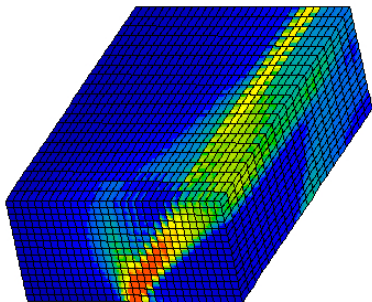


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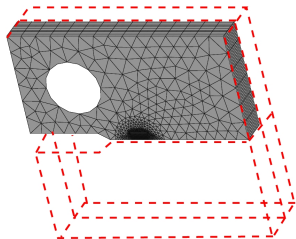
◀ Start ▶ Tension ▶ Rotation ▶ End



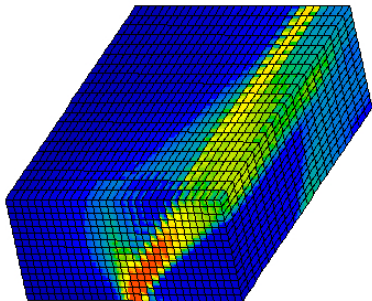
3D analyses - Orientation $K \propto (110)[001]$



◀ Start ▶ Tension ▶ Rotation ▶ End

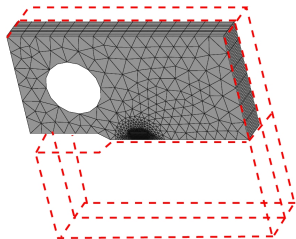


3D analyses - Orientation $K \propto (110)[001]$

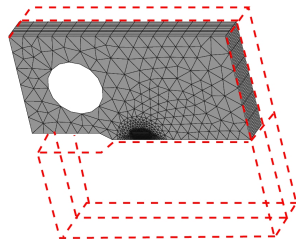
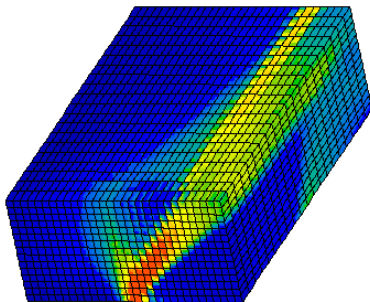


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

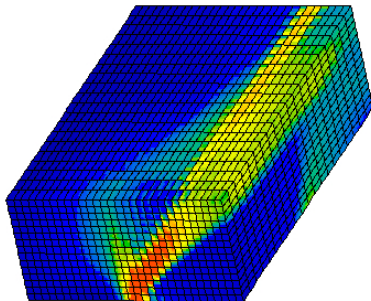


3D analyses - Orientation $K \sim (110)[001]$



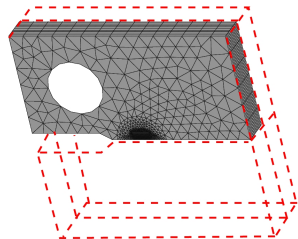
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3D analyses - Orientation $K \sim (110)[001]$

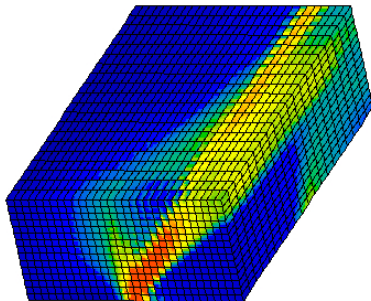


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

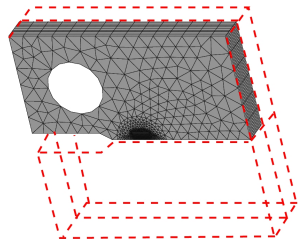


3D analyses - Orientation $K \propto (110)[001]$

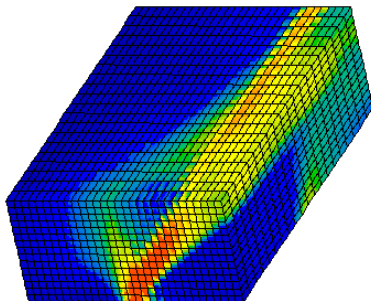


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

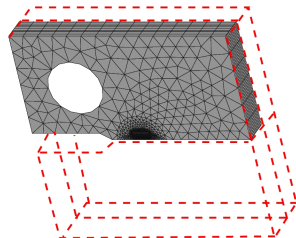


3D analyses - Orientation $K \propto (110)[001]$

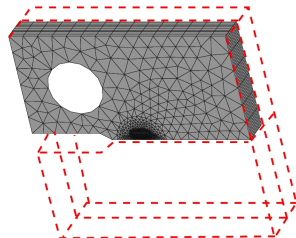
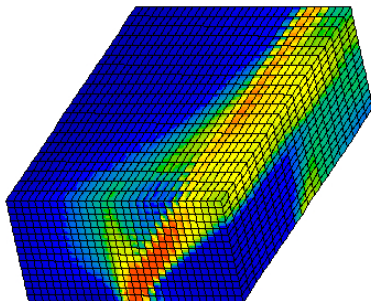


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

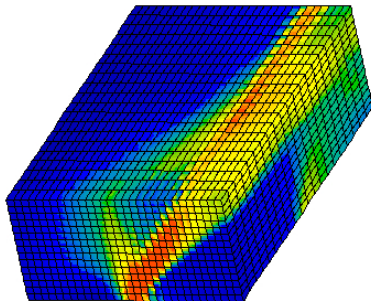


3D analyses - Orientation $K \propto (110)[001]$



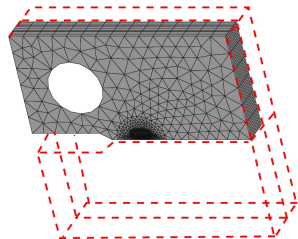
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3D analyses - Orientation $K \propto (110)[001]$

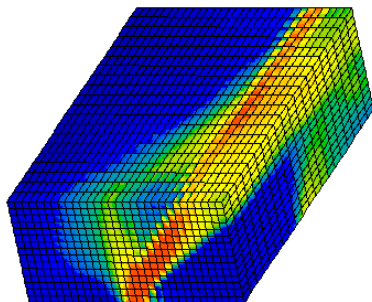


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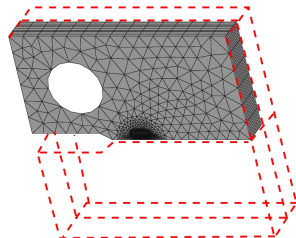


3D analyses - Orientation $K \sim (110)[001]$

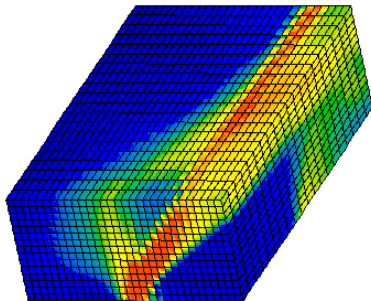


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

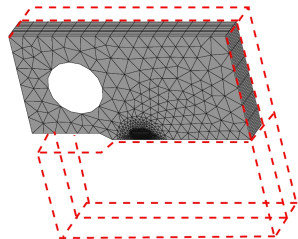


3D analyses - Orientation $K \propto (110)[001]$

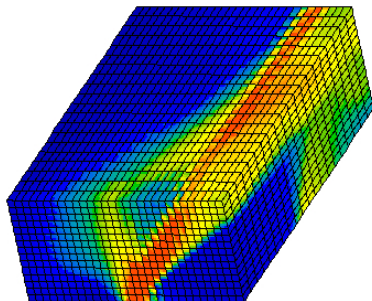


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◀ Start ▶ Tension ▶ Rotation ▶ End

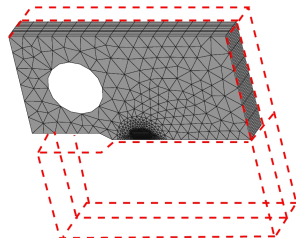


3D analyses - Orientation $K \propto (110)[001]$

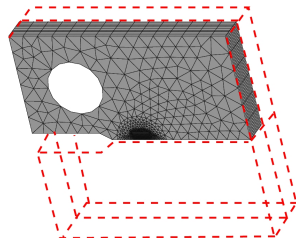
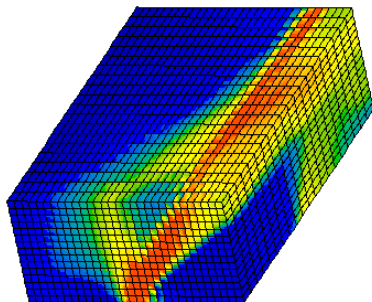


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◀ Start ▶ Tension ▶ Rotation ▶ End

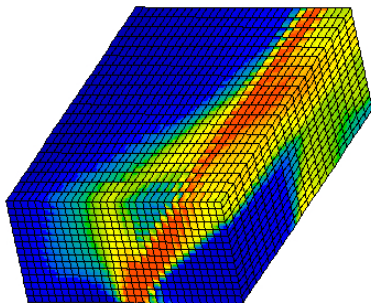


3D analyses - Orientation $K \propto (110)[001]$



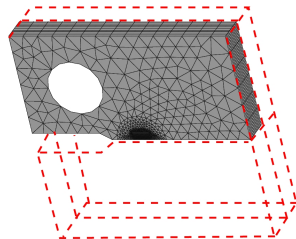
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3D analyses - Orientation $K \sim (110)[001]$

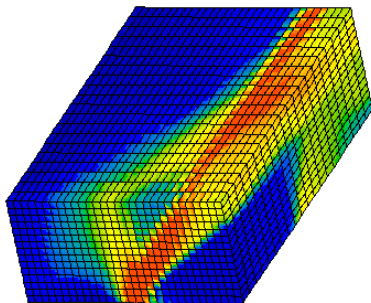


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

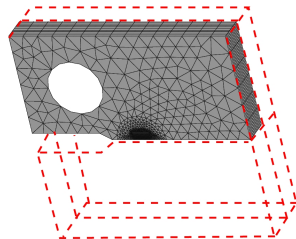


3D analyses - Orientation $K \sim (110)[001]$

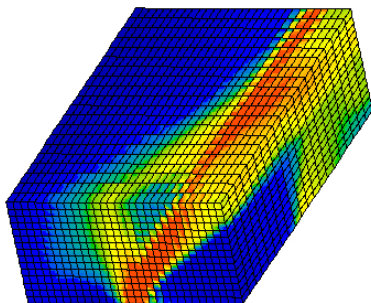


1.5mm

◀ Start ▶ Tension ▶ Rotation ▶ End

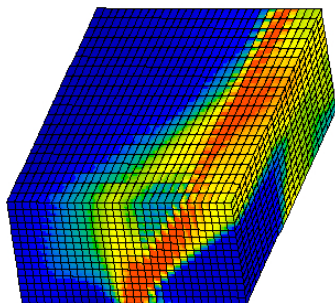


3D analyses - Orientation K $\gamma(110)[001]$



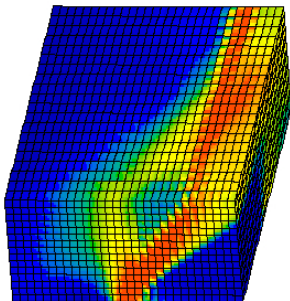
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3D analyses - Orientation K γ (110)[001]



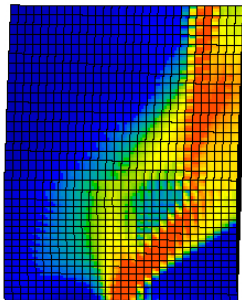
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3D analyses - Orientation K γ (110)[001]



◀ Start ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation K γ (110)[001]



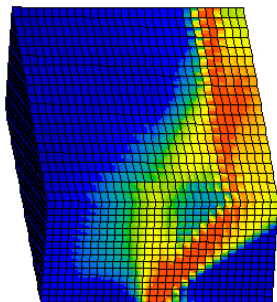
◀ Start

▶ Tension

▶ Rotation

▶ End

3D analyses - Orientation K γ (110)[001]



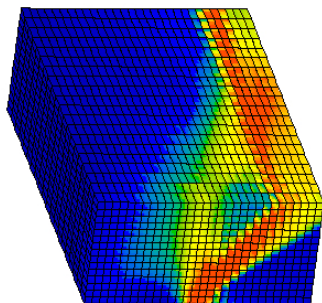
◀ Start

▶ Tension

▶ Rotation

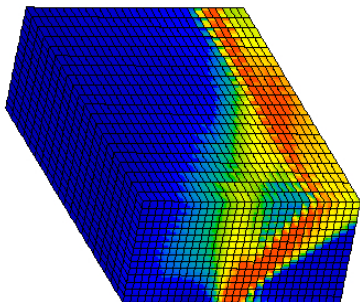
▶ End

3D analyses - Orientation K γ (110)[001]



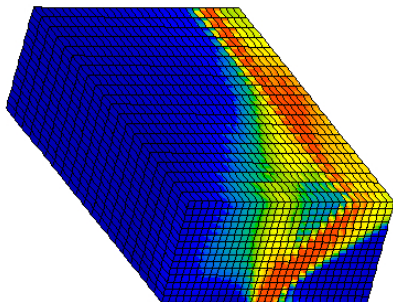
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3D analyses - Orientation $K \propto (110)[001]$



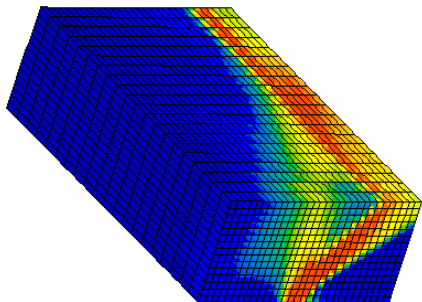
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3D analyses - Orientation K γ (110)[001]



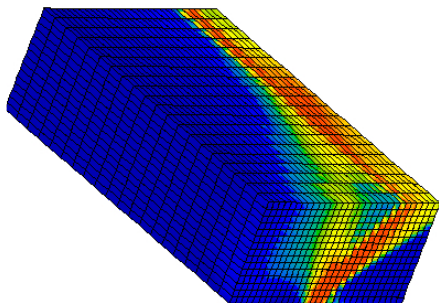
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3D analyses - Orientation $K \propto (110)[001]$



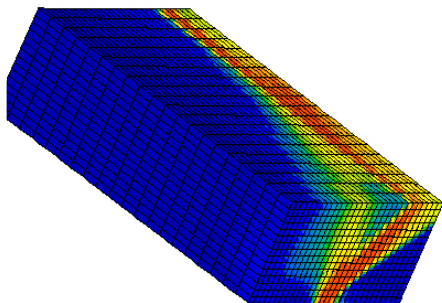
◀ Start ▶ Tension ▶ Rotation ▶ End

3D analyses - Orientation $K \propto (110)[001]$



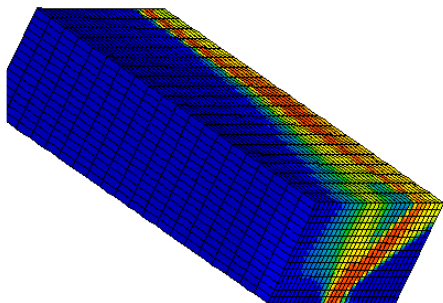
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3D analyses - Orientation $K \sim (110)[001]$



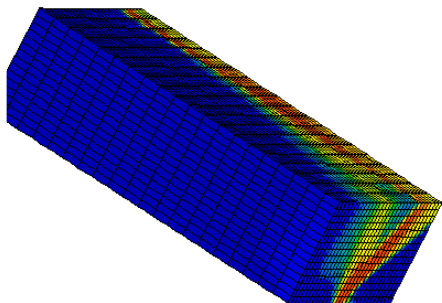
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3D analyses - Orientation $K \propto (110)[001]$



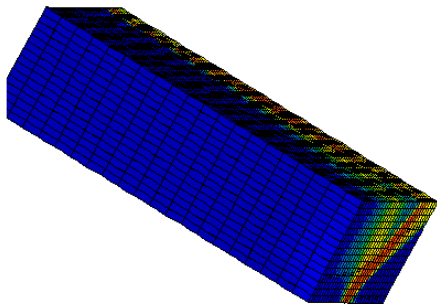
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3D analyses - Orientation $K \propto (110)[001]$



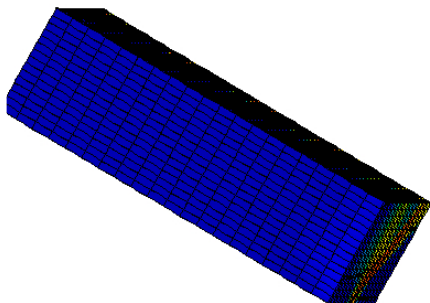
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3D analyses - Orientation $K \sim (110)[001]$



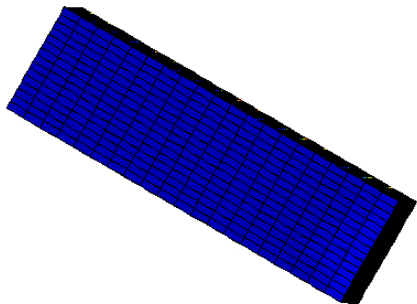
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3D analyses - Orientation $K \sim (110)[001]$



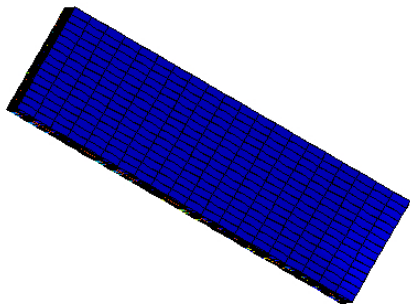
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3D analyses - Orientation $K \sim (110)[001]$



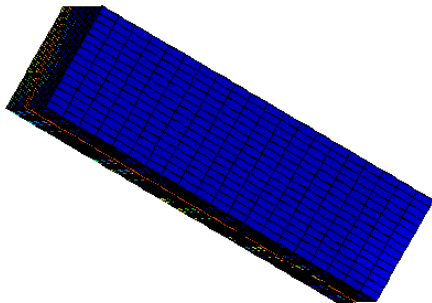
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3D analyses - Orientation K γ (110)[001]



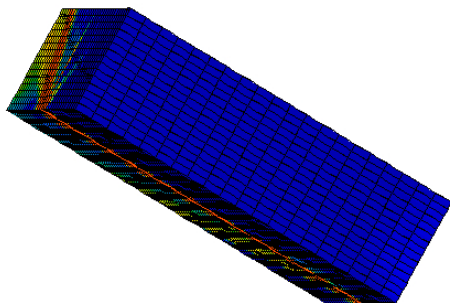
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3D analyses - Orientation $K \propto (110)[001]$



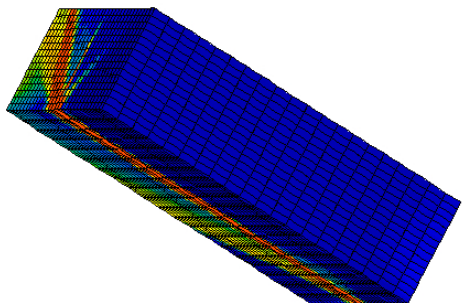
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3D analyses - Orientation $K \sim (110)[001]$



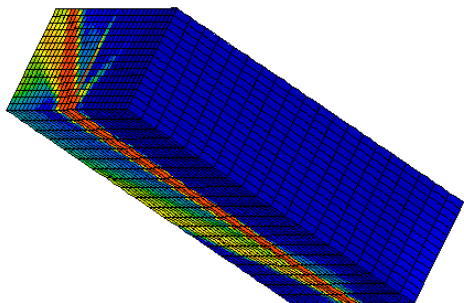
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3D analyses - Orientation $K \sim (110)[001]$



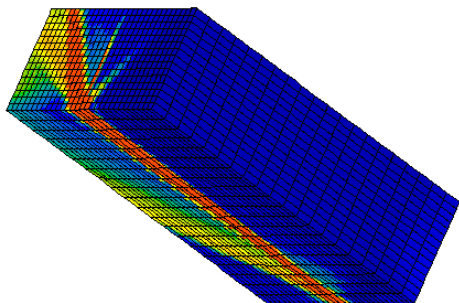
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3D analyses - Orientation $K \sim (110)[001]$



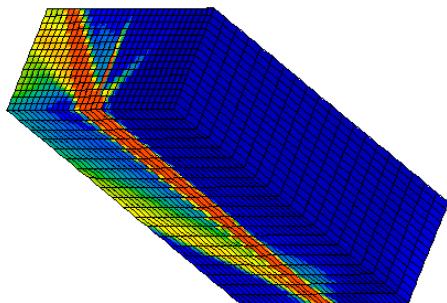
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3D analyses - Orientation $K \sim (110)[001]$



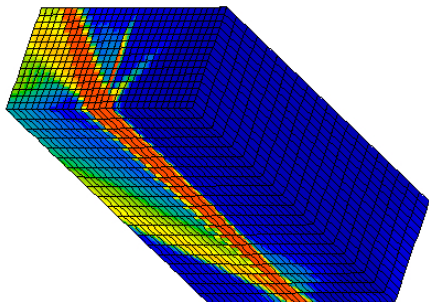
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3D analyses - Orientation $K \searrow (110)[001]$



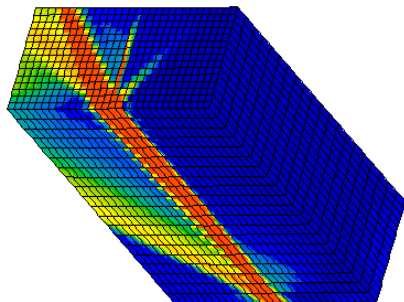
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3D analyses - Orientation $K \searrow (110)[001]$



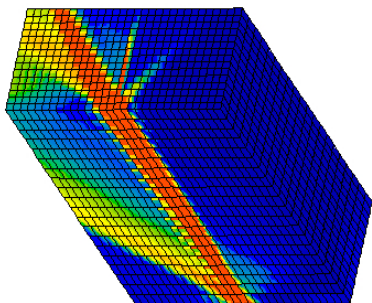
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3D analyses - Orientation $K \sim (110)[001]$



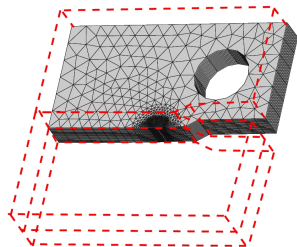
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3D analyses - Orientation $K \sim (110)[001]$

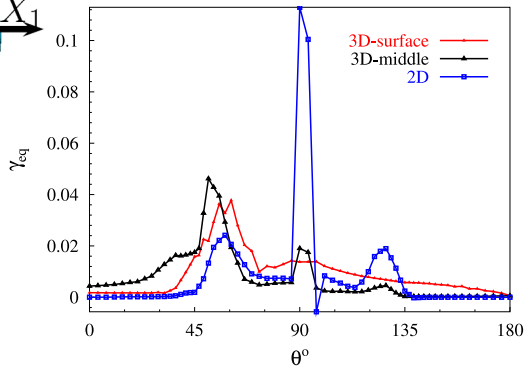
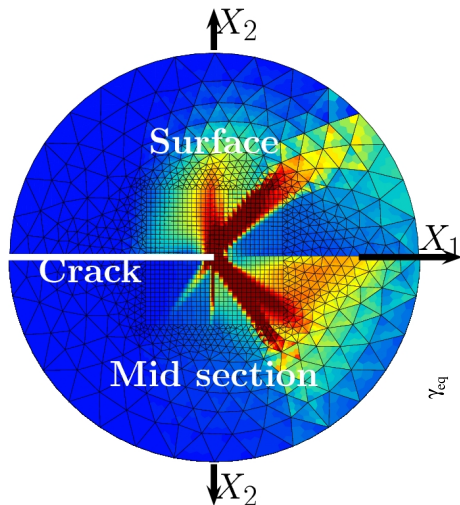


1.5mm

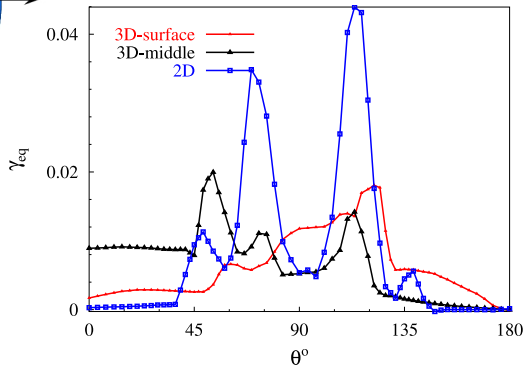
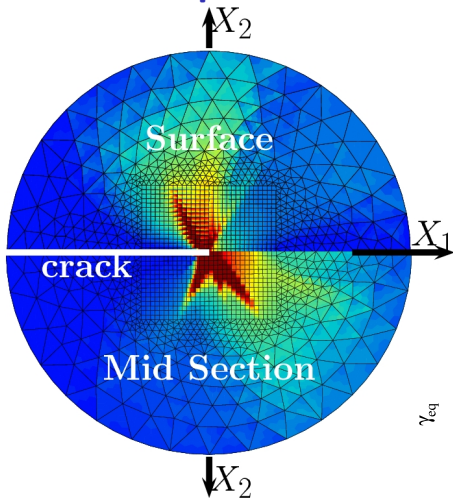
◀ Start ▶ Tension ▶ Rotation ▶ End



Comparison surface-core - Orientation K



Comparison surface-core - Orientation C



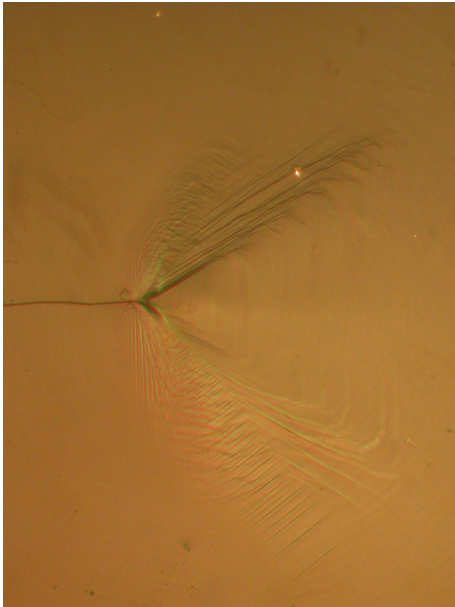
Plan

- 1 Introduction
- 2 Rice's solution of the crack problem in SX
 - Plane strain and effective slip systems
 - Balance of momentum; field equations
 - Extension of the solutions
- 3 3D effects on the crack tip fields
 - Loading conditions
 - Comparison surface-core
- 4 Confrontation to experimental results
- 5 Application to fatigue
 - Deformation at the crack tip under cyclic loading
 - Crack propagation paths
- 6 Conclusions-perspectives

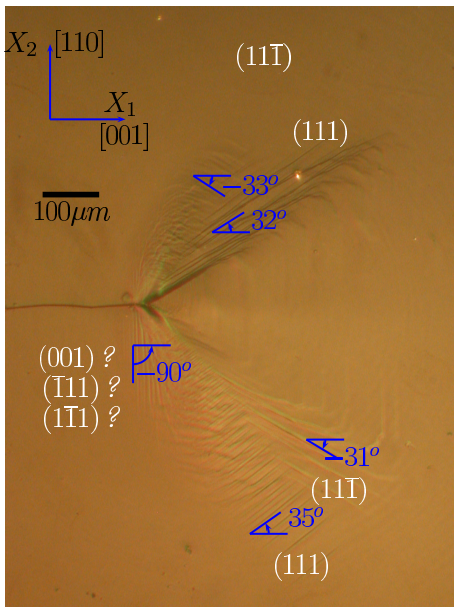
Experimental approach

- Mechanical testing
 - ① CT specimen
 - ② Pre-cracking at 650°C
 - decreasing ΔK
 - $R=0.1$
 - ③ Polishing
 - ④ Monotonous tension at 20°C
- Observation means
 - ① Optical-SEM (indexing slip planes)
 - ② Roughness measurement (out-of-plane displacement)
 - ③ EBSD - Lattice rotation

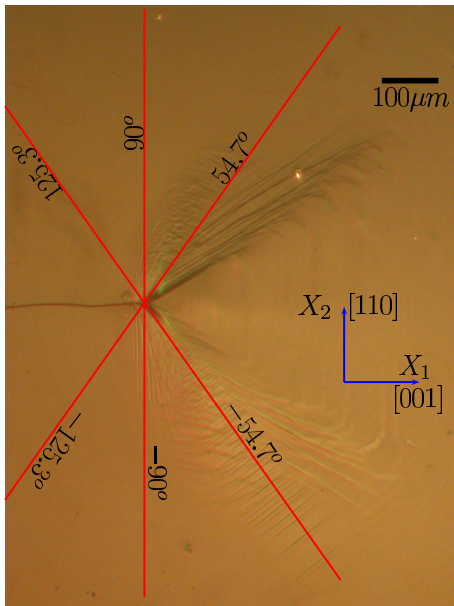
Test: crack with orientation $K \rightarrow (110)[001]$



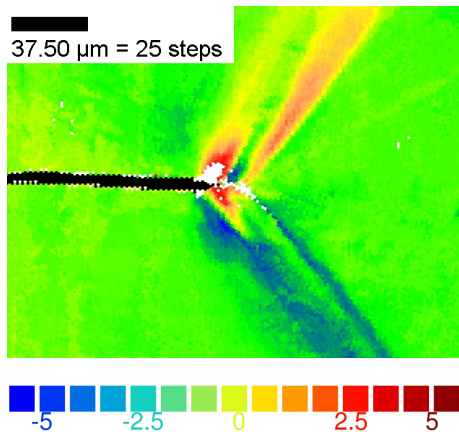
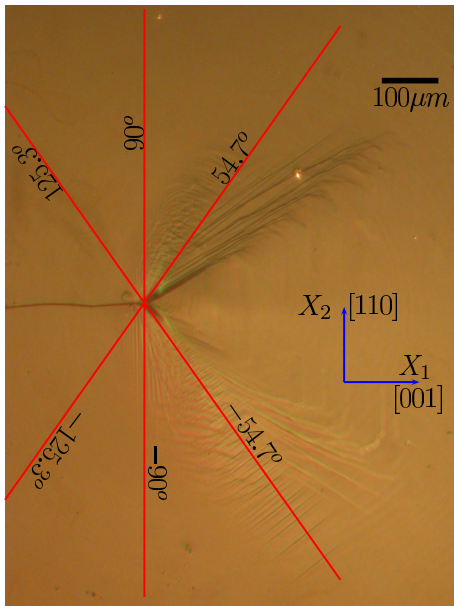
Test: crack with orientation $K \sim (110)[001]$



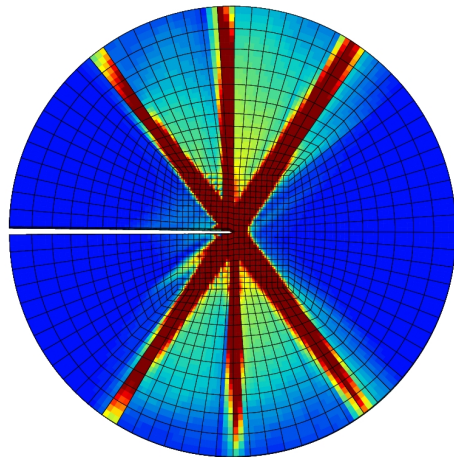
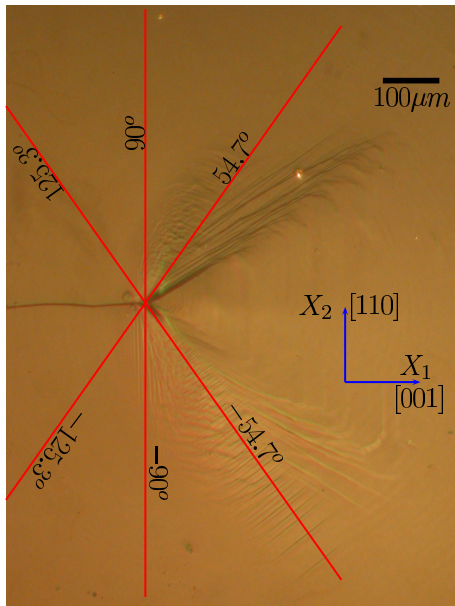
Test: crack with orientation $K \gamma (110)[001]$



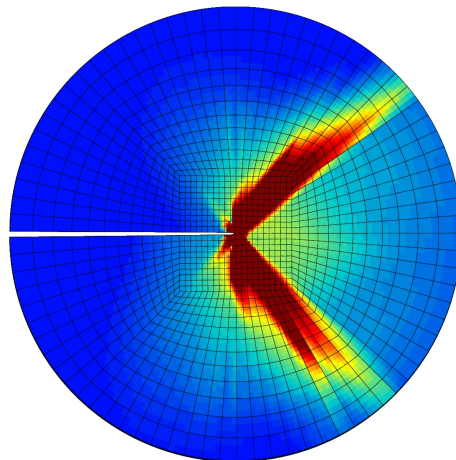
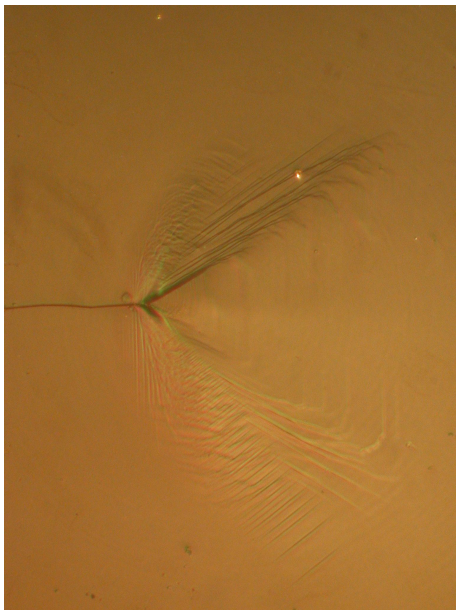
Test: crack with orientation $K \searrow (110)[001]$



Test: crack with orientation $K \sim (110)[001]$

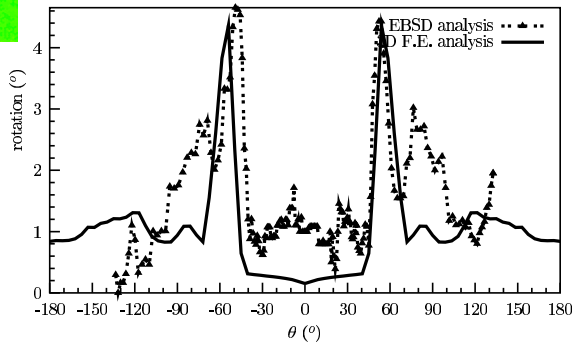
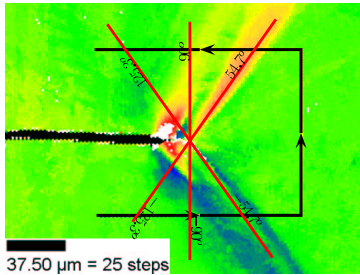


Test: crack with orientation $K \sim (110)[001]$

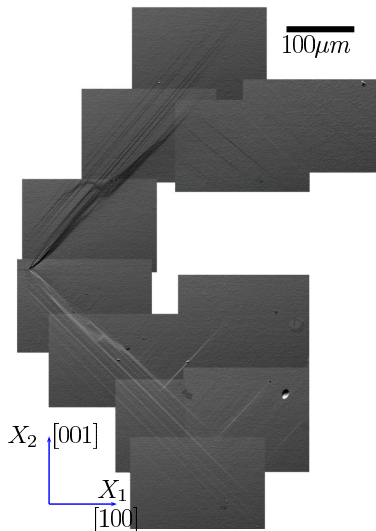


200 μm

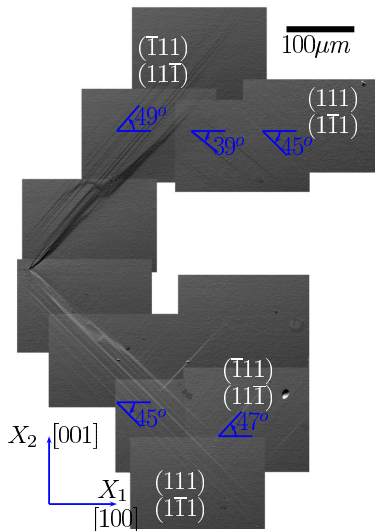
Test: crack with orientation $K \sim (110)[001]$



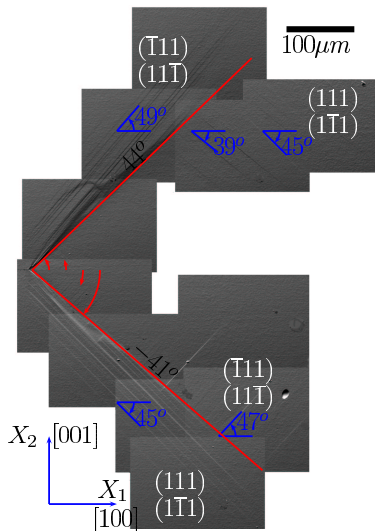
Test: crack with orientation $C \sim (001)[100]$



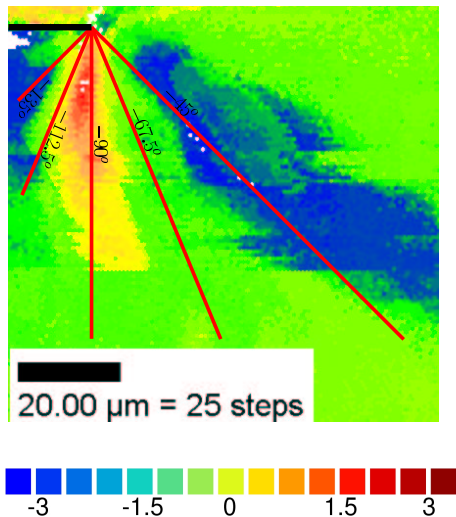
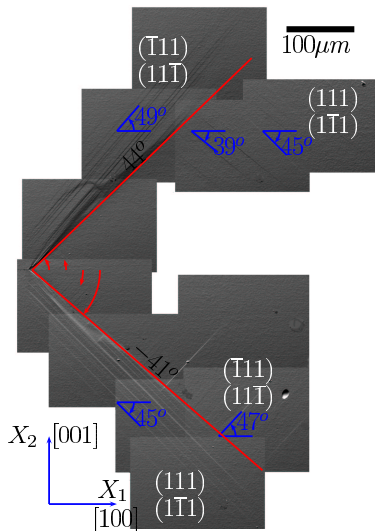
Test: crack with orientation $C \sim (001)[100]$



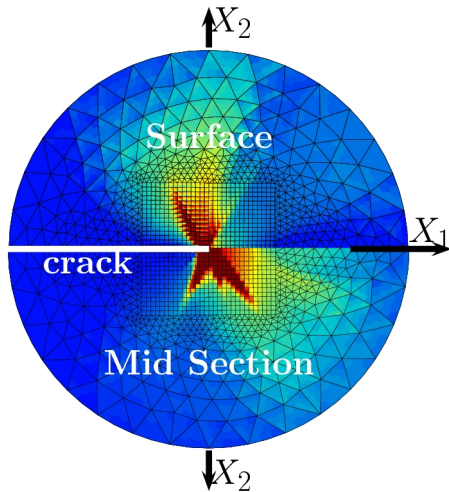
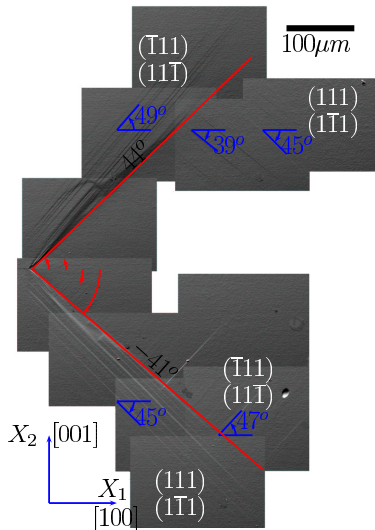
Test: crack with orientation $C \sim (001)[100]$



Test: crack with orientation $C \prec (001)[100]$

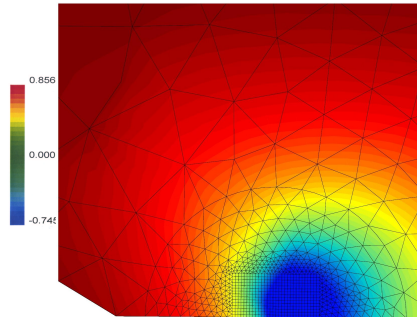
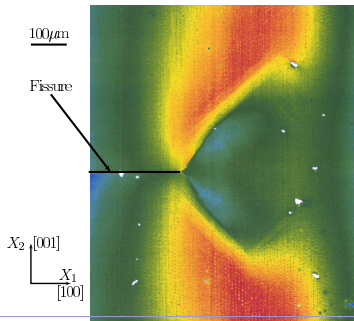
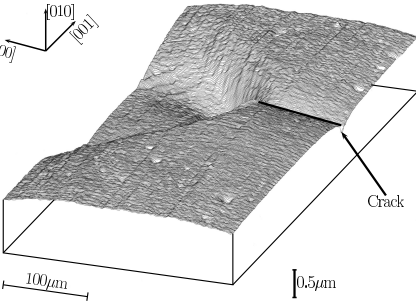


Test: crack with orientation $C \prec (001)[100]$



Test: crack with orientation $C \sim (001)[100]$

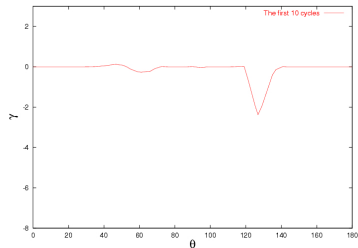
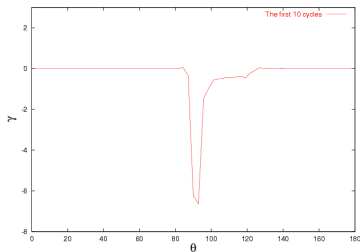
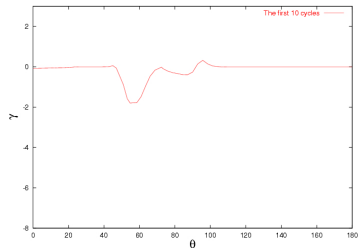
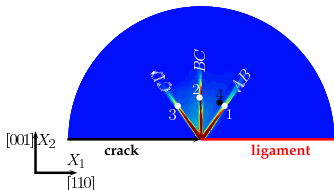
out-of-plane displacement



Plan

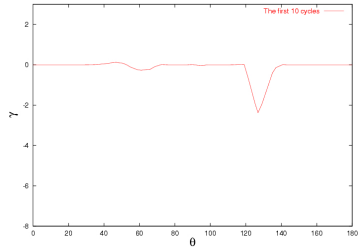
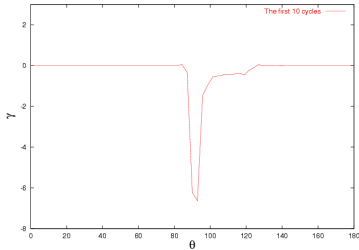
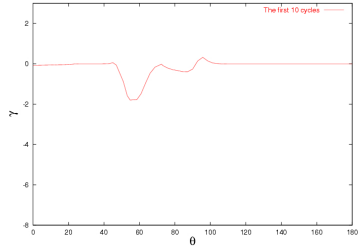
- 1 Introduction
- 2 Rice's solution of the crack problem in SX
 - Plane strain and effective slip systems
 - Balance of momentum; field equations
 - Extension of the solutions
- 3 3D effects on the crack tip fields
 - Loading conditions
 - Comparison surface-core
- 4 Confrontation to experimental results
- 5 Application to fatigue
 - Deformation at the crack tip under cyclic loading
 - Crack propagation paths
- 6 Conclusions-perspectives

Cyclic loading - orientation $\gamma(001)[110]$



► Start ► Animation ►► End

Cyclic loading - orientation $\gamma(001)[110]$

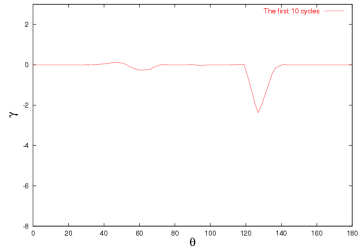
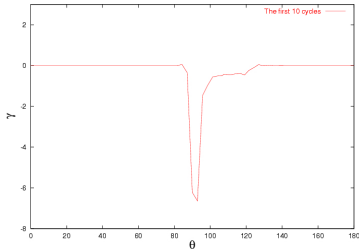
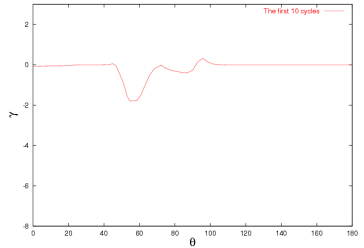
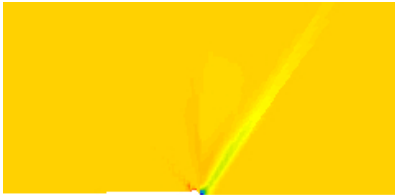


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

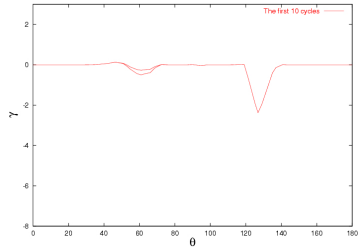
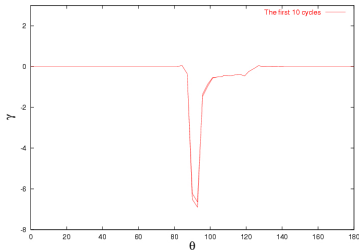
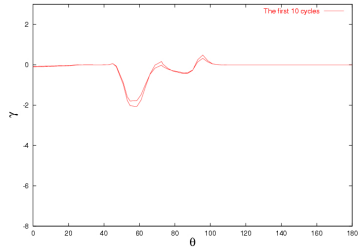
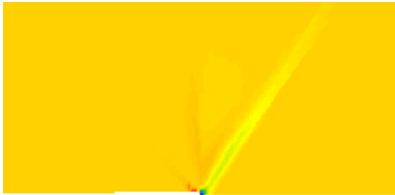


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

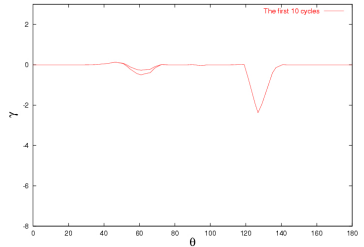
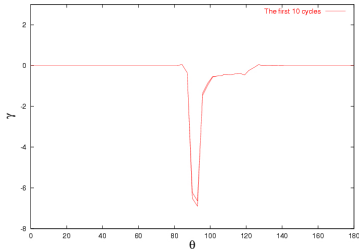
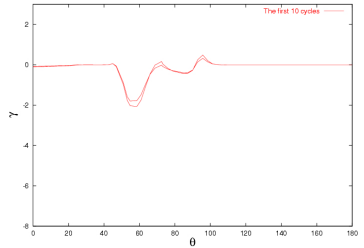
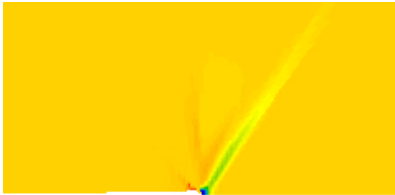


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

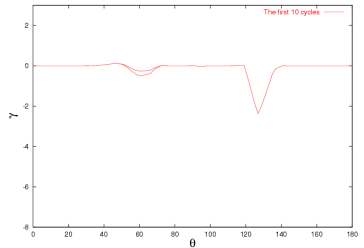
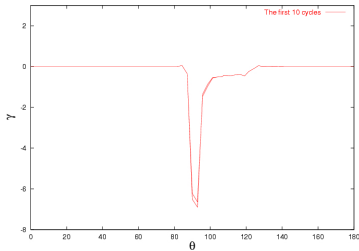
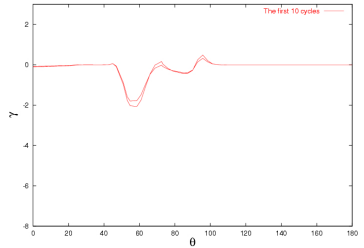
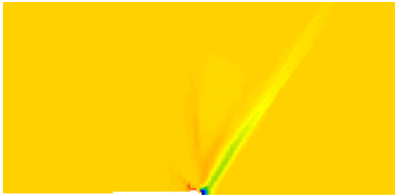


► Start

► Animation

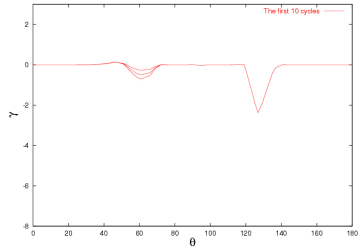
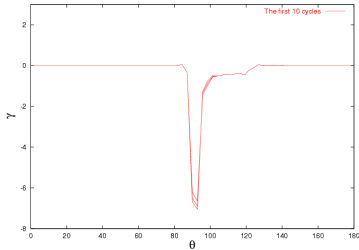
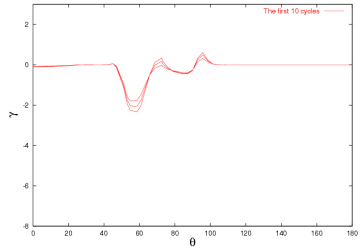
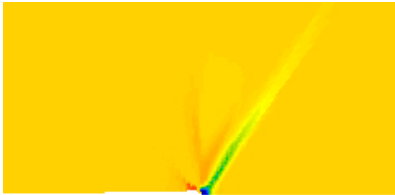
►► End

Cyclic loading - orientation $\gamma(001)[110]$



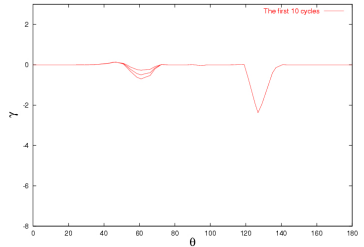
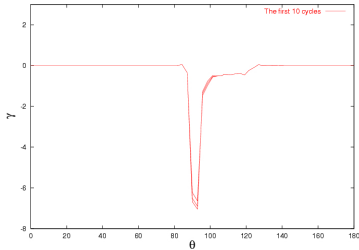
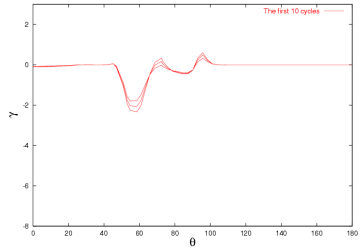
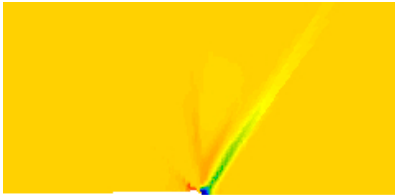
► Start ► Animation ►► End

Cyclic loading - orientation $\gamma(001)[110]$



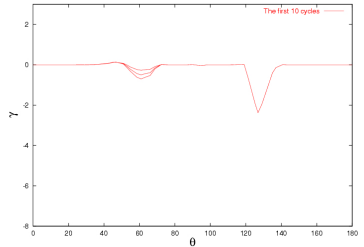
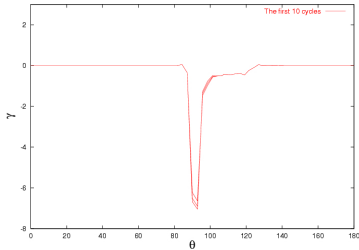
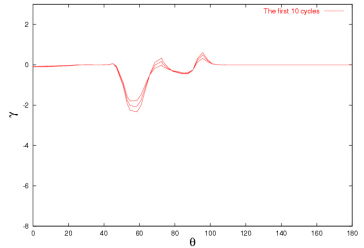
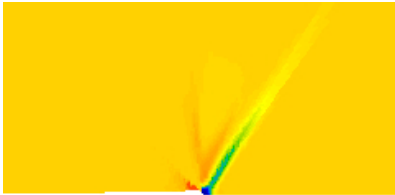
► Start ► Animation ►► End

Cyclic loading - orientation $\gamma(001)[110]$



► Start ► Animation ►► End

Cyclic loading - orientation $\gamma(001)[110]$

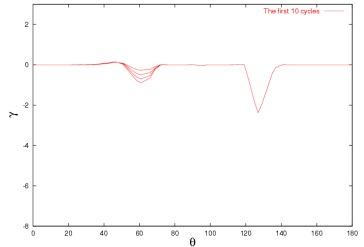
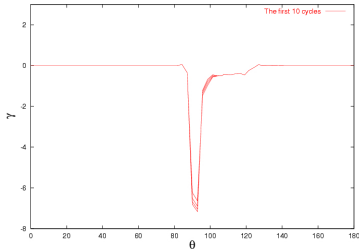
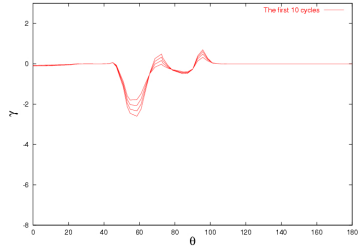
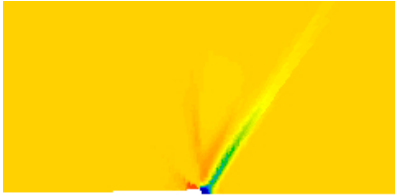


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

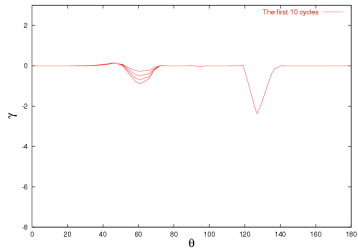
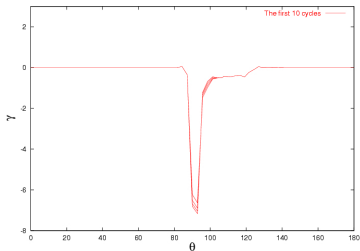
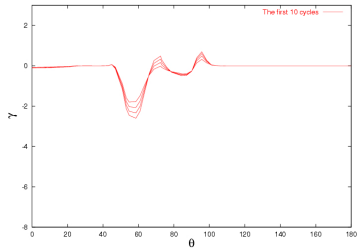
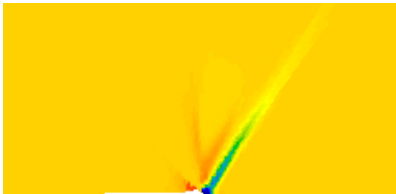


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

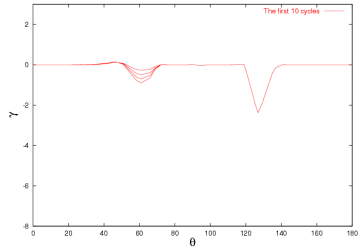
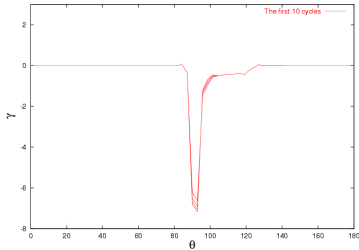
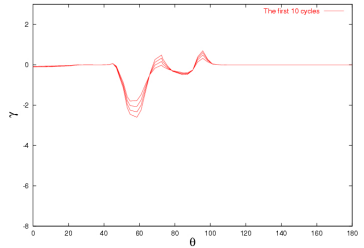
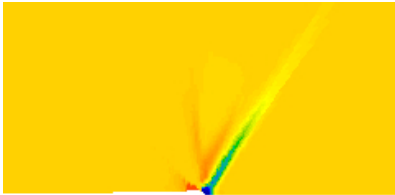


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

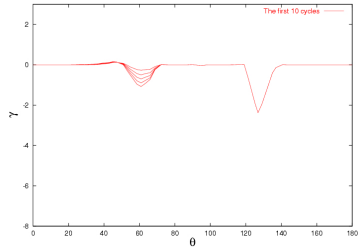
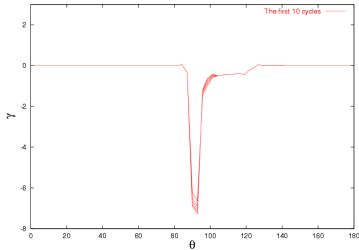
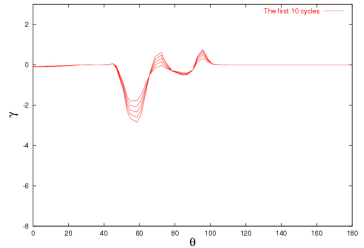
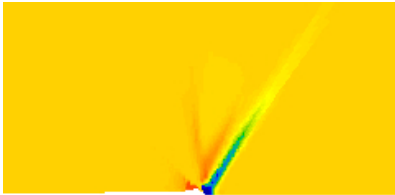


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

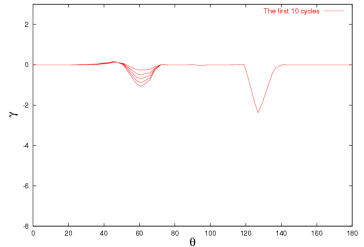
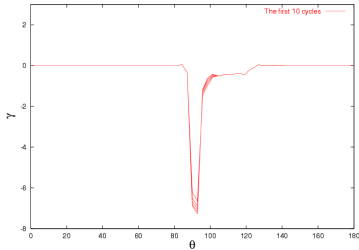
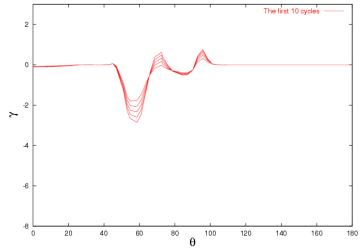
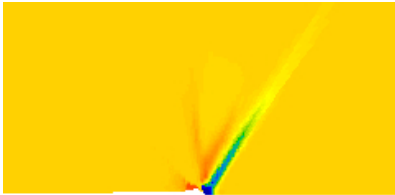


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

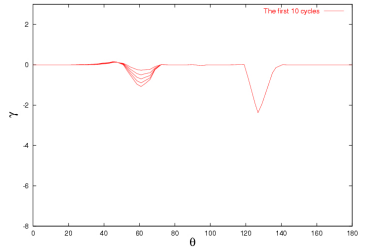
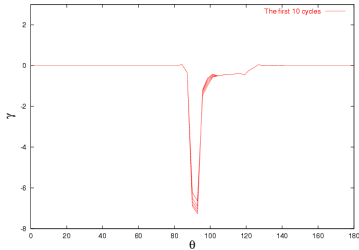
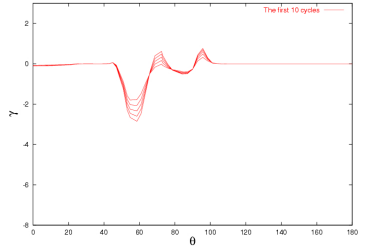
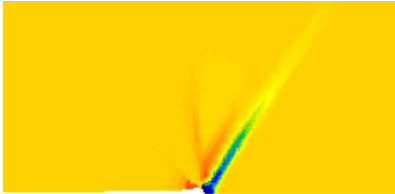


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

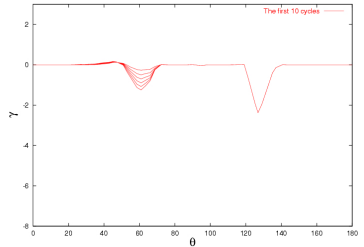
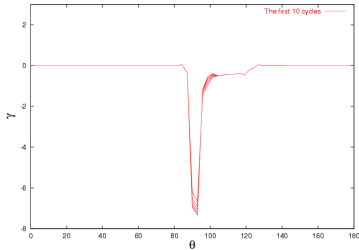
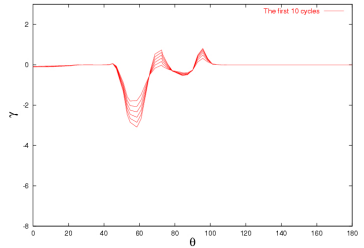
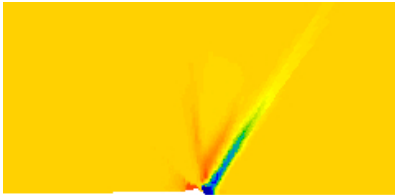


► Start

► Animation

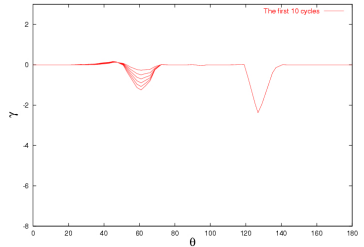
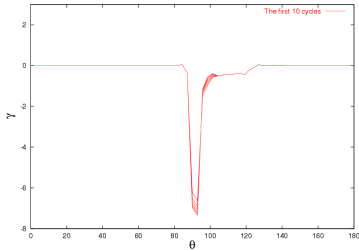
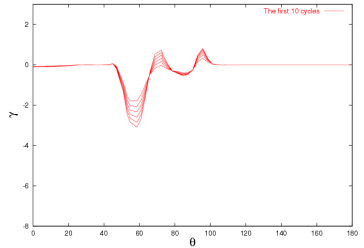
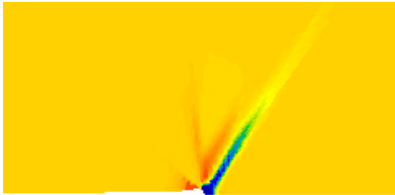
►► End

Cyclic loading - orientation $\gamma(001)[110]$



► Start ► Animation ►► End

Cyclic loading - orientation $\gamma(001)[110]$

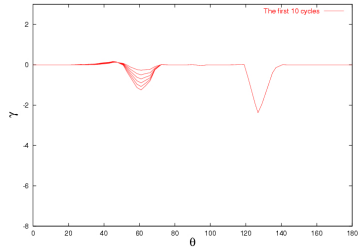
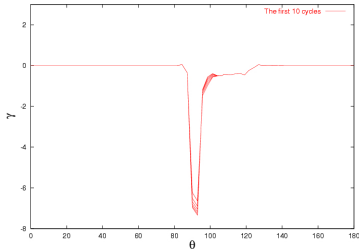
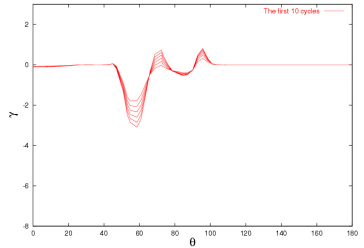
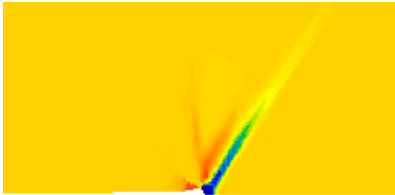


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

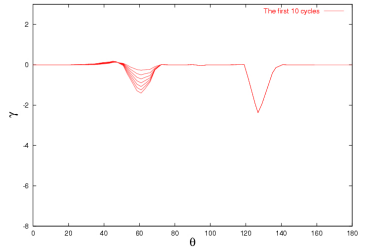
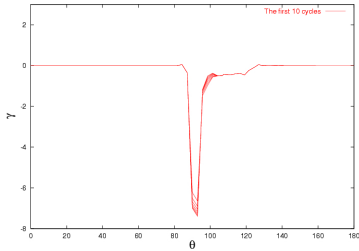
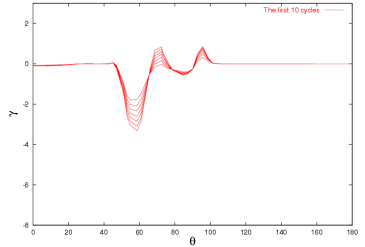
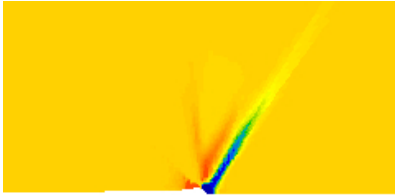


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

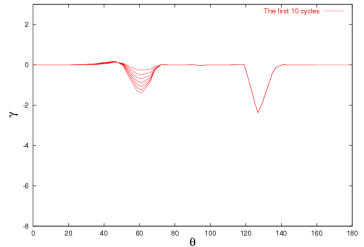
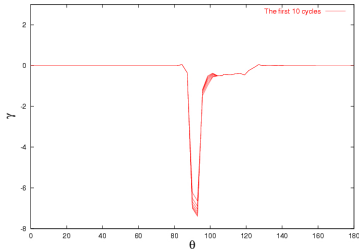
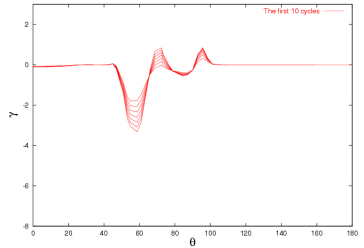
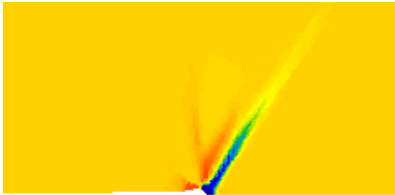


► Start

► Animation

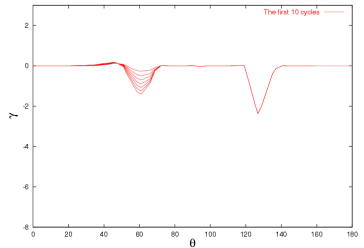
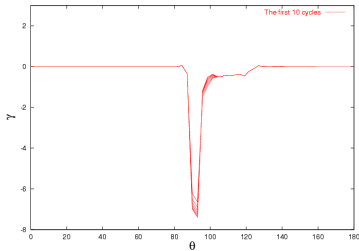
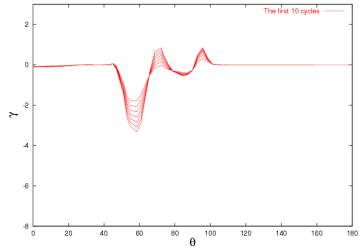
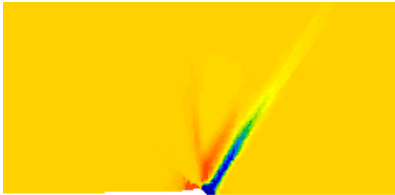
►► End

Cyclic loading - orientation $\gamma(001)[110]$



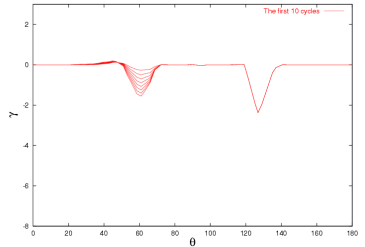
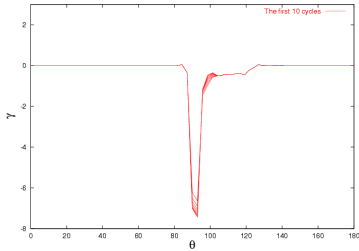
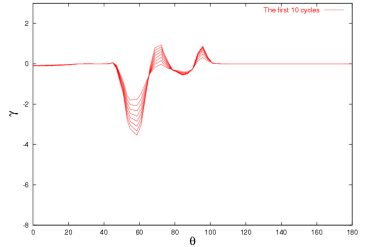
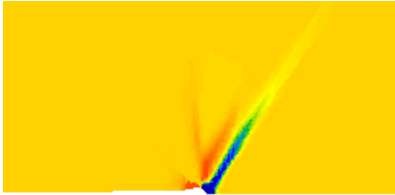
► Start ► Animation ►► End

Cyclic loading - orientation $\gamma(001)[110]$



► Start ► Animation ►► End

Cyclic loading - orientation $\gamma(001)[110]$

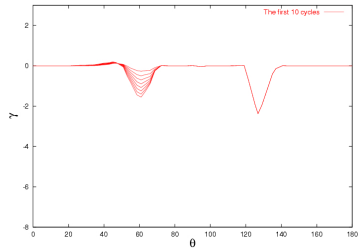
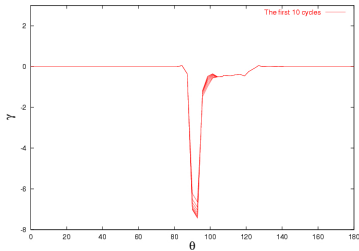
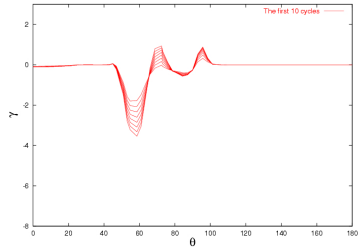
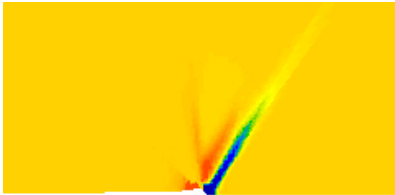


► Start

► Animation

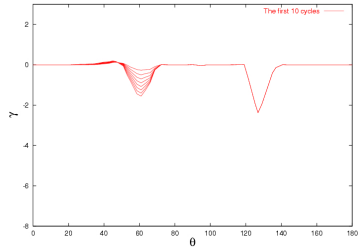
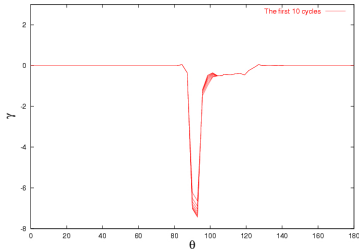
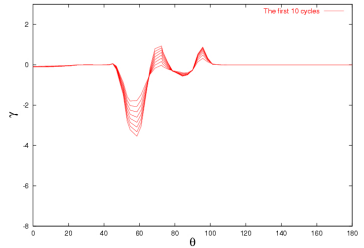
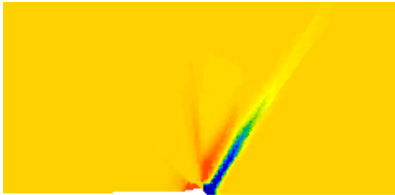
►► End

Cyclic loading - orientation $\gamma(001)[110]$



► Start ► Animation ►► End

Cyclic loading - orientation $\gamma(001)[110]$

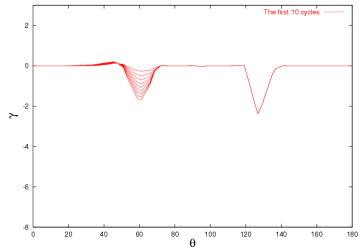
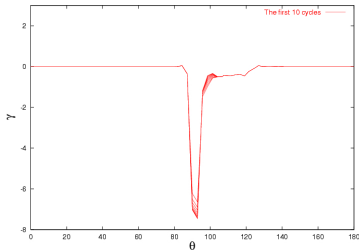
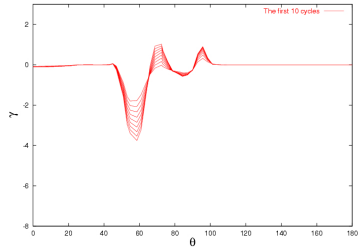
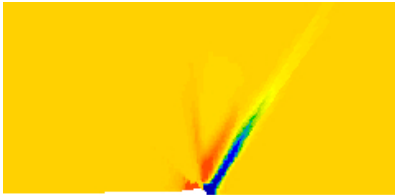


► Start

► Animation

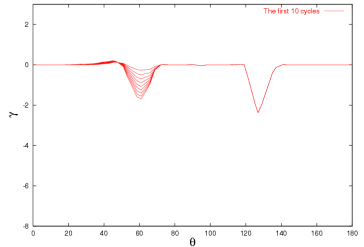
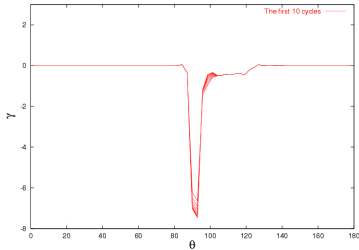
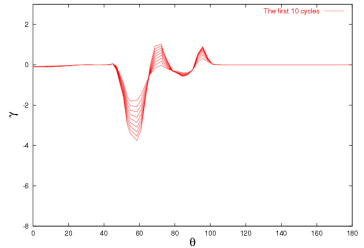
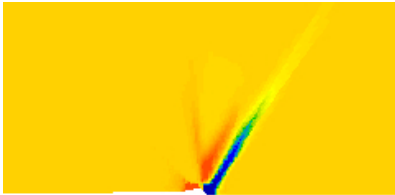
►► End

Cyclic loading - orientation $\gamma(001)[110]$



► Start ► Animation ►► End

Cyclic loading - orientation $\gamma(001)[110]$

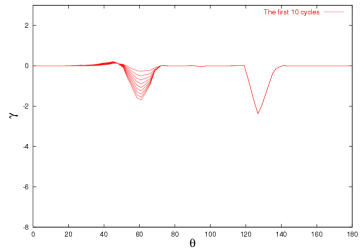
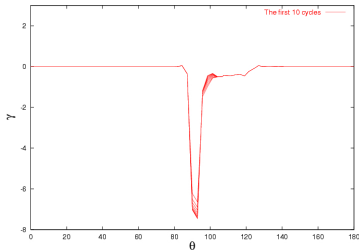
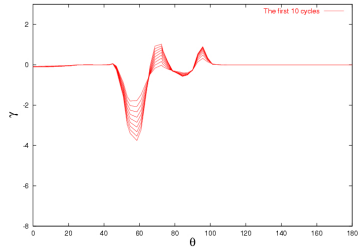
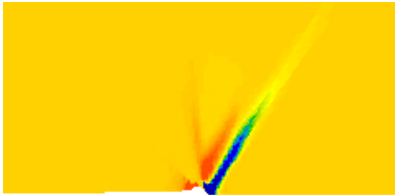


► Start

► Animation

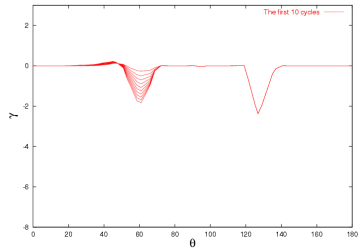
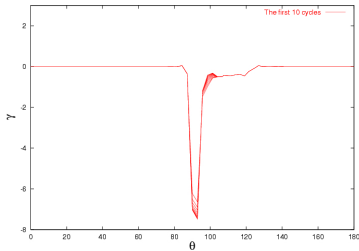
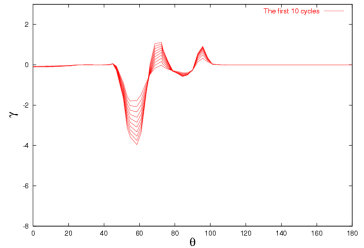
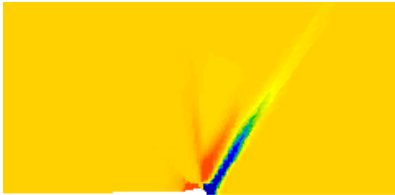
►► End

Cyclic loading - orientation $\gamma(001)[110]$



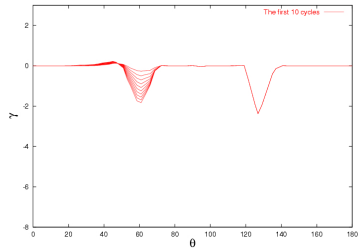
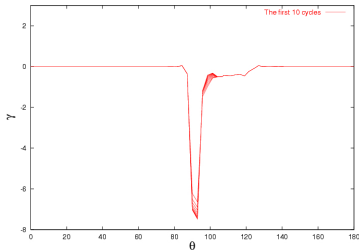
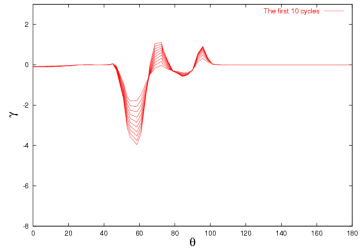
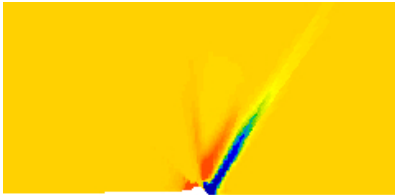
► Start ► Animation ►► End

Cyclic loading - orientation $\gamma(001)[110]$



► Start ► Animation ►► End

Cyclic loading - orientation $\gamma(001)[110]$

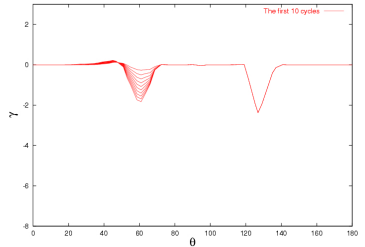
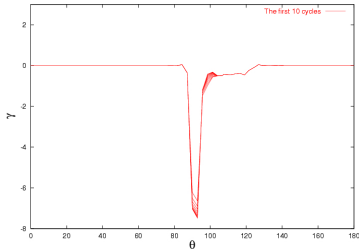
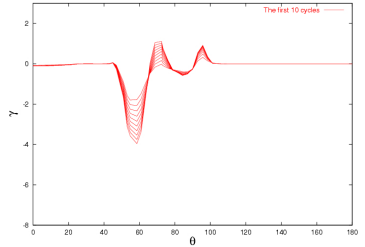
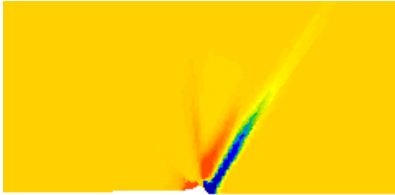


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

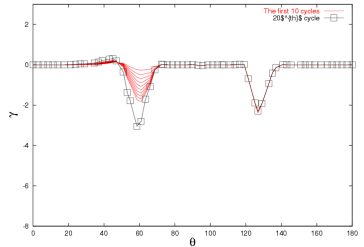
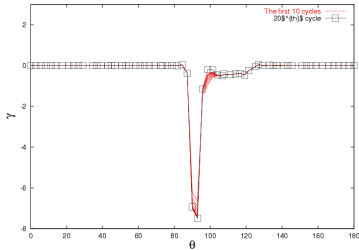
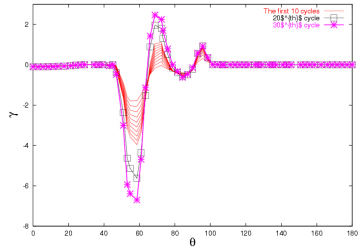
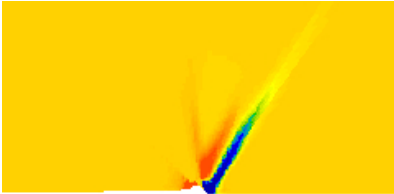


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

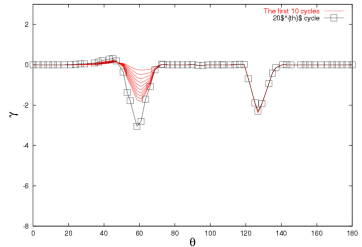
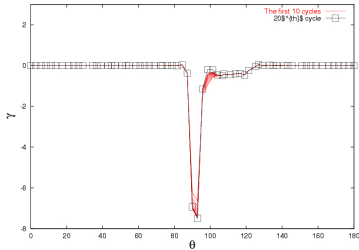
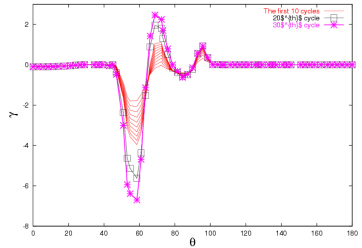
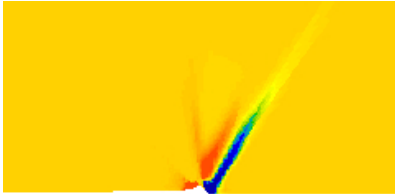


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

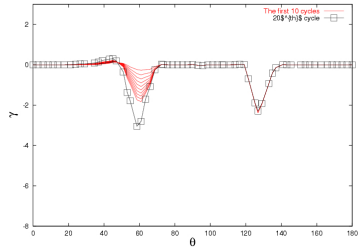
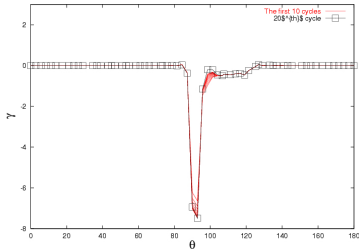
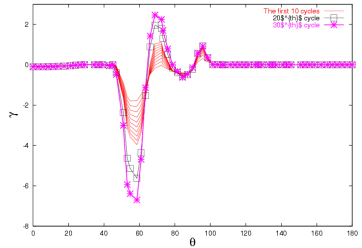
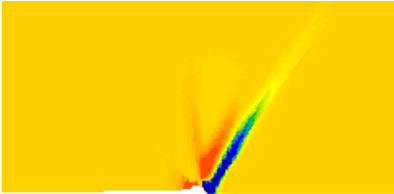


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

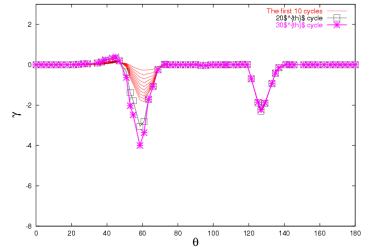
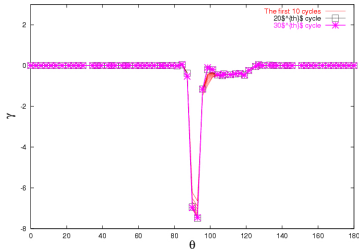
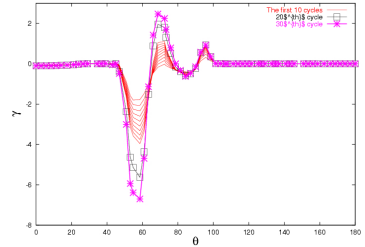
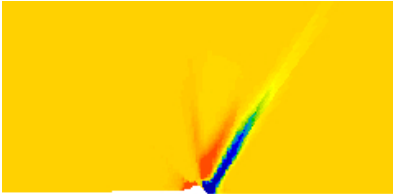


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

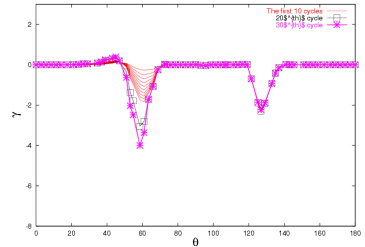
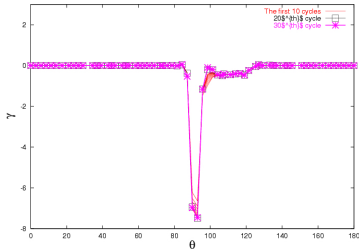
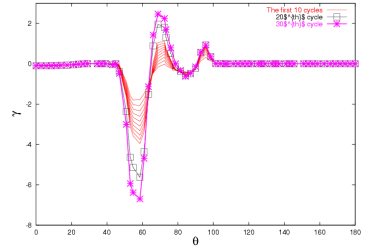
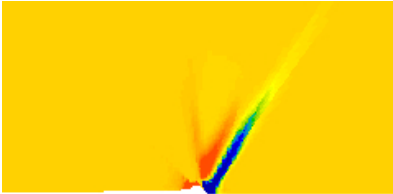


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

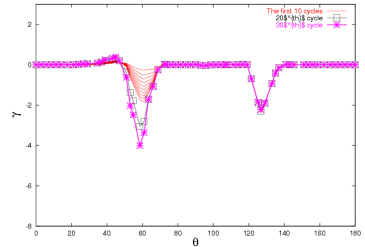
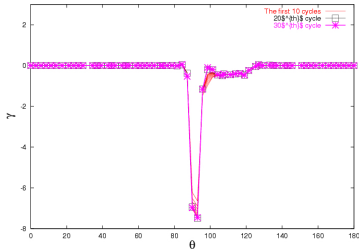
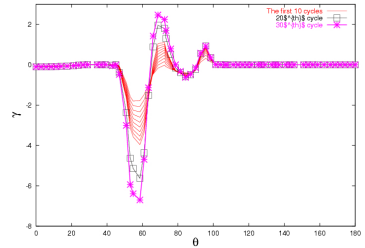
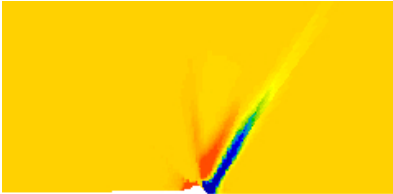


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

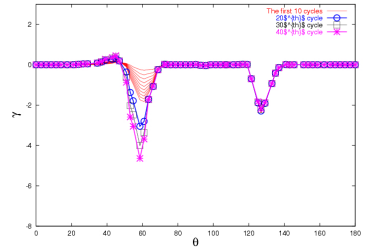
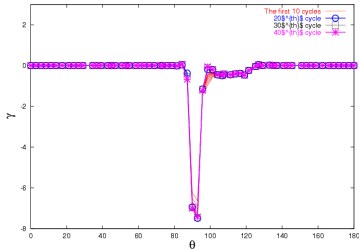
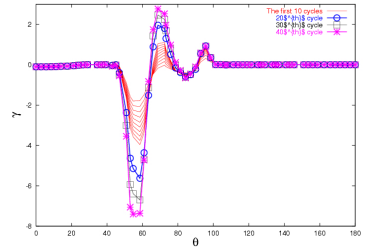
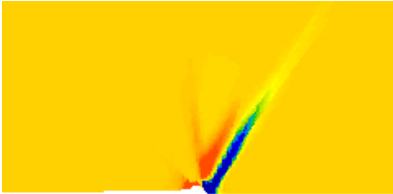


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

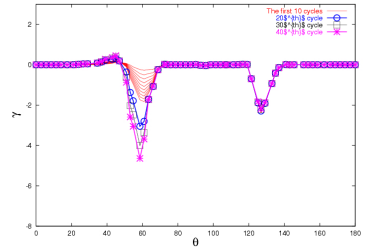
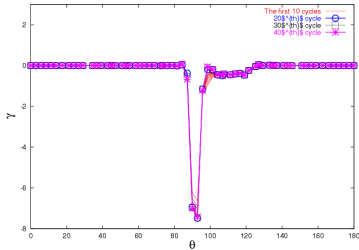
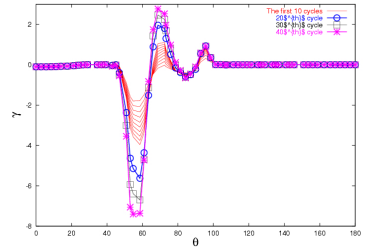
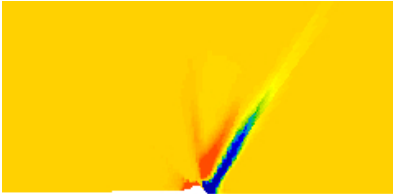


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

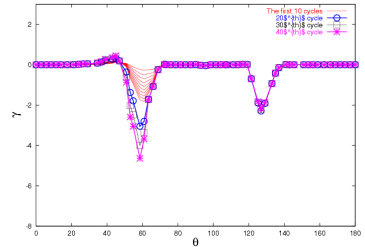
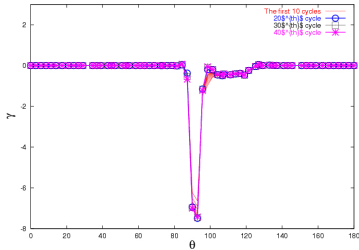
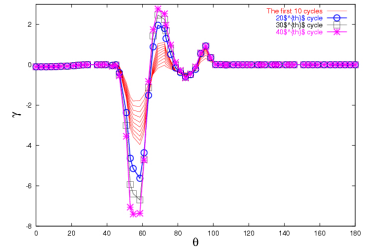
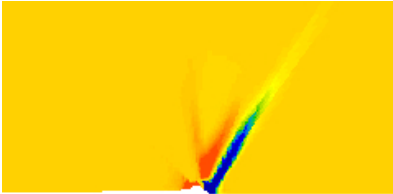


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

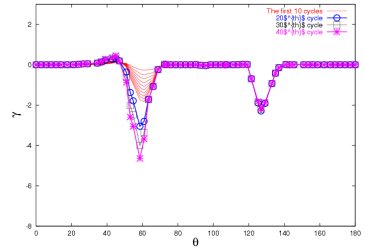
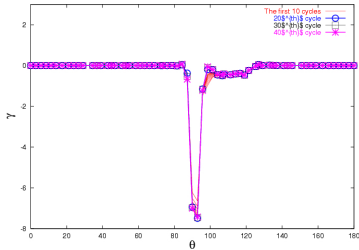
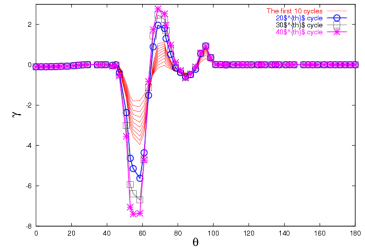
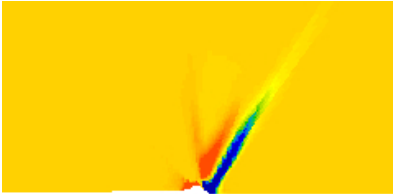


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

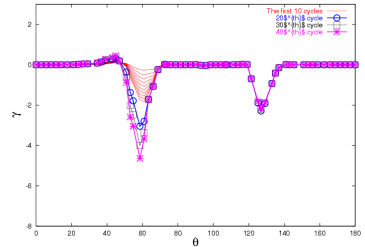
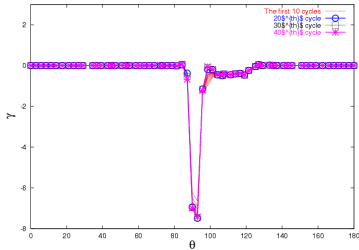
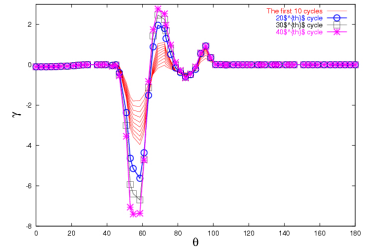
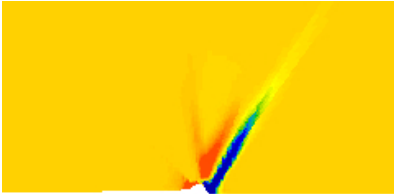


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

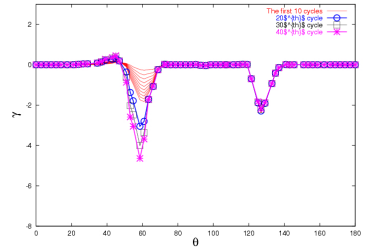
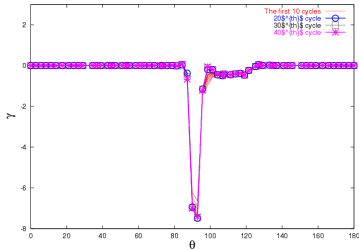
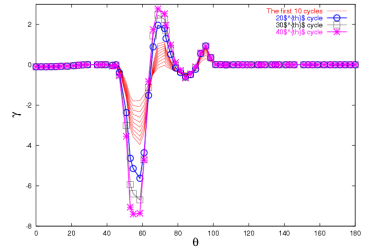
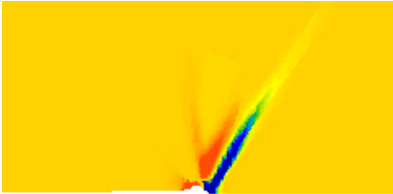


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$

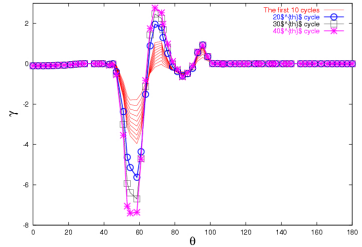
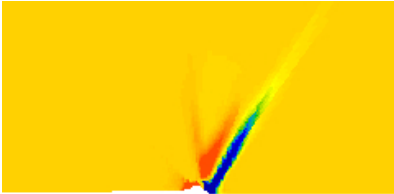


► Start

► Animation

►► End

Cyclic loading - orientation $\gamma(001)[110]$



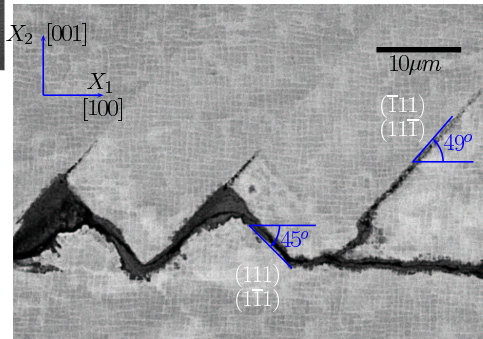
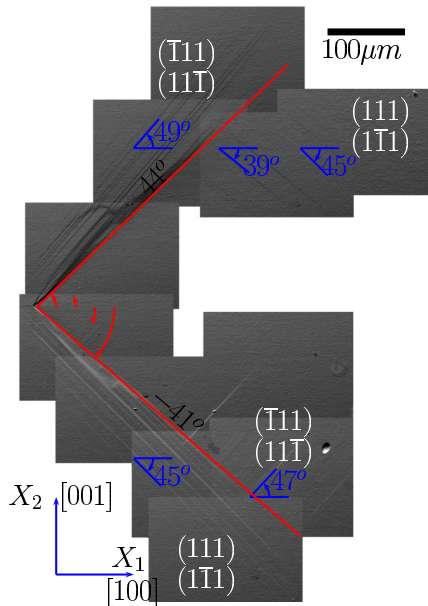
- only the band ahead of the crack tip continues to deform during cycling
- ratchetting

► Start ► Animation ►► End

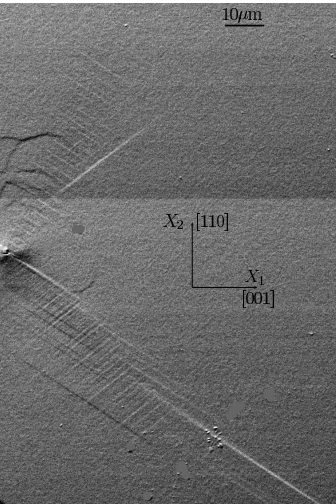
Plan

- 1 Introduction
- 2 Rice's solution of the crack problem in SX
 - Plane strain and effective slip systems
 - Balance of momentum; field equations
 - Extension of the solutions
- 3 3D effects on the crack tip fields
 - Loading conditions
 - Comparison surface-core
- 4 Confrontation to experimental results
- 5 Application to fatigue
 - Deformation at the crack tip under cyclic loading
 - Crack propagation paths
- 6 Conclusions-perspectives

Crack path C

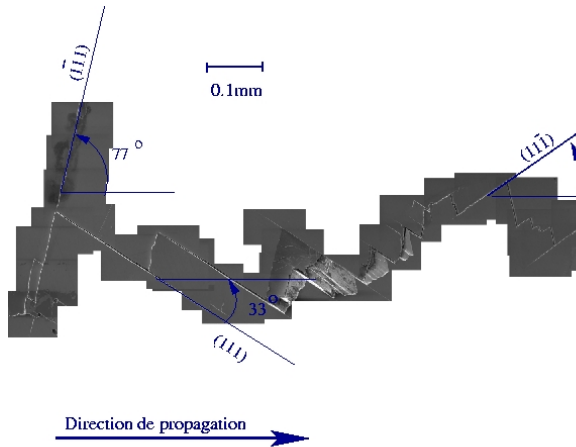
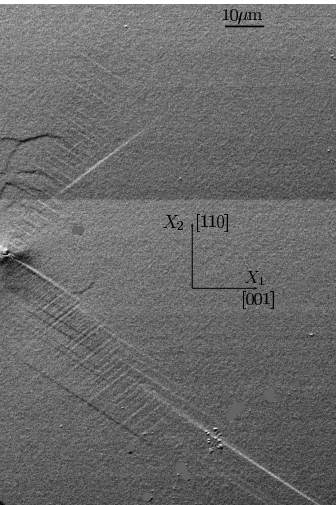


Crack path K



- pre-cracking at $650^{\circ}C$
- monotonic loading at $20^{\circ}C$
- observation of the strain field
- cyclic loading at $20^{\circ}C$
- observation of the crack path

Crack path K



Conclusions

- The continuum approach can be applied at the crack tip
providing that :

- real crystal orientation
- 3D computation
- introduce work-hardening

But :

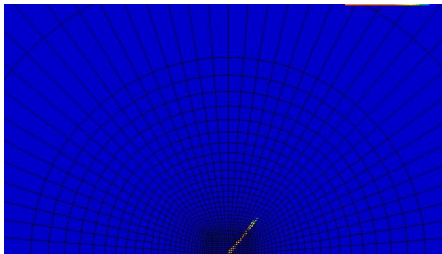
- crack orientation $\succ (001)[100]$ is more complex (number of activated slip systems)
- New aspects:
 - Observation of the existence of kink bands
 - Cube slip lines were not confirmed \longrightarrow additional tests
 - Impact of strain localization at the crack tip of subsequent crack growth

Perspectives

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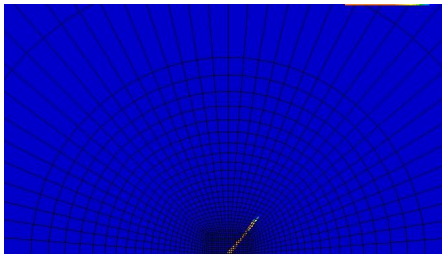
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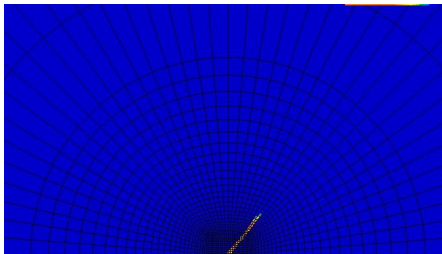
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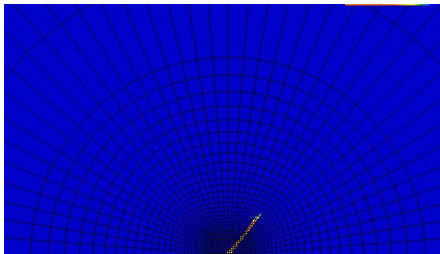
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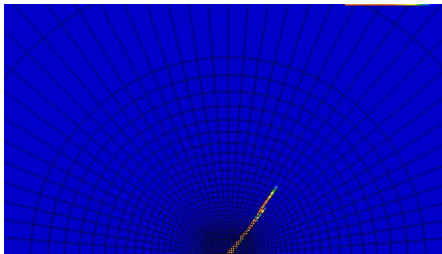
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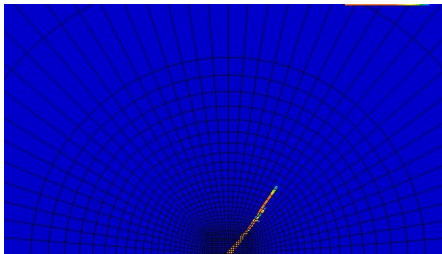
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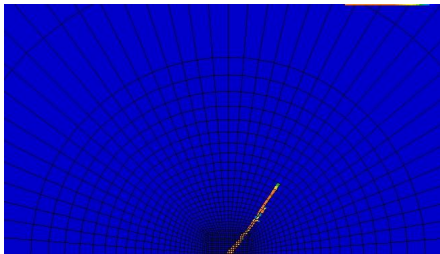
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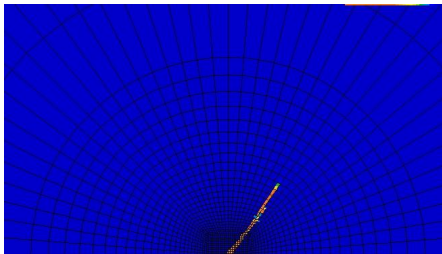
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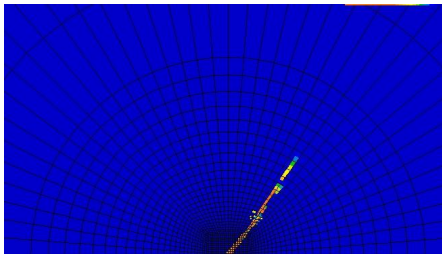
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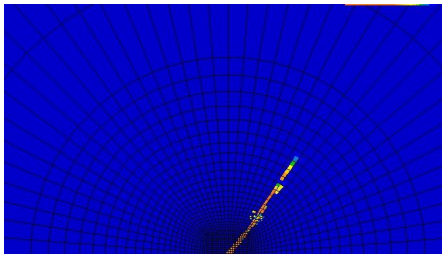
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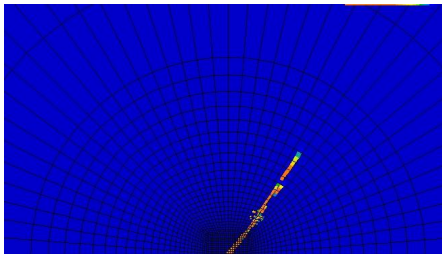
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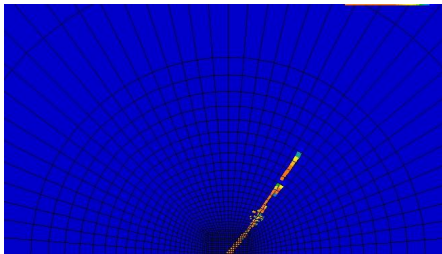
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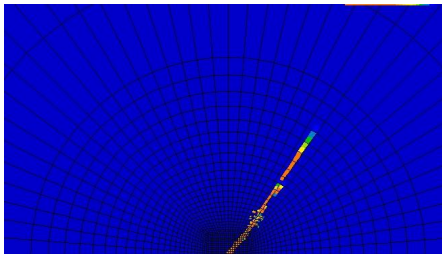
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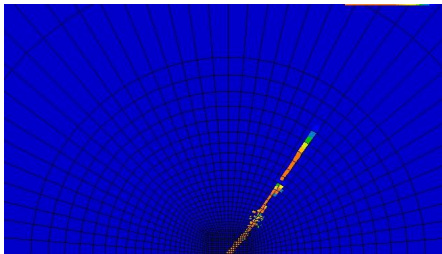
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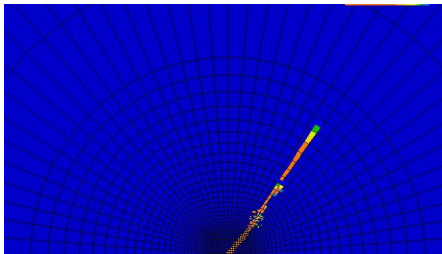
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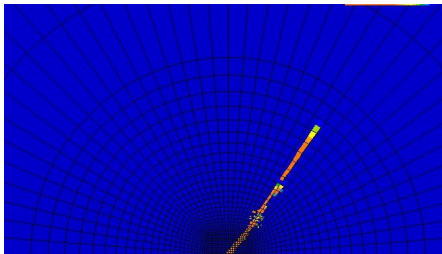
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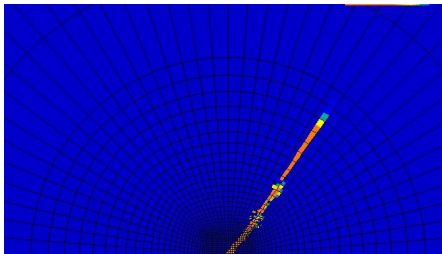
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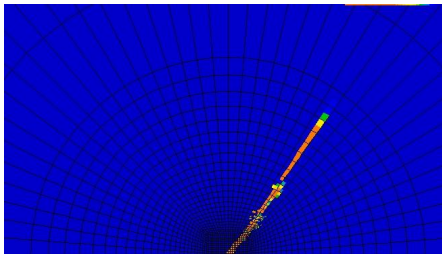
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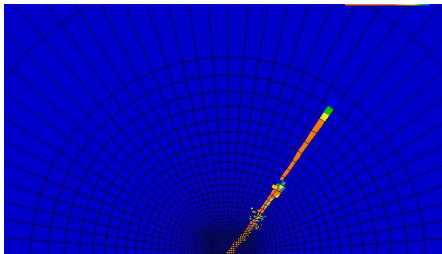
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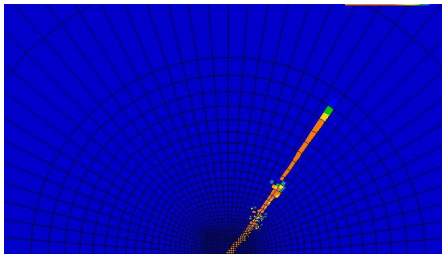
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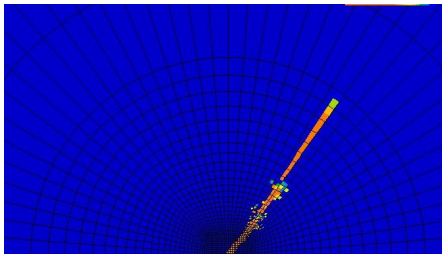
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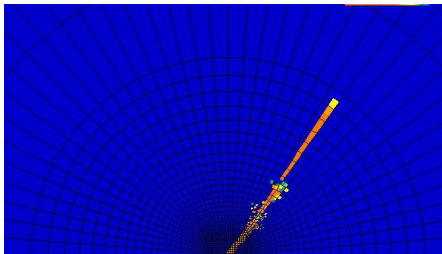
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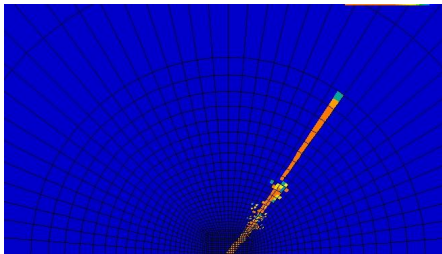
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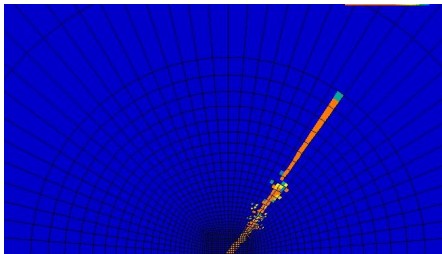
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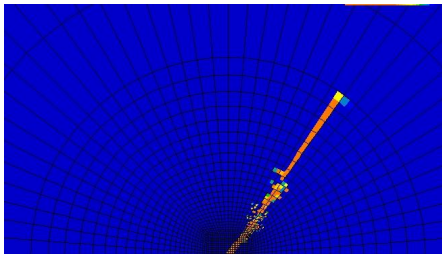
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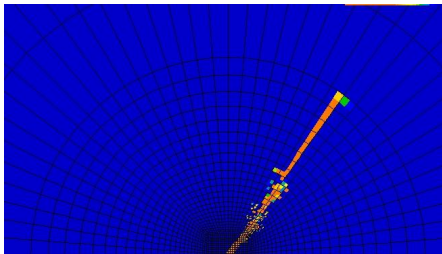
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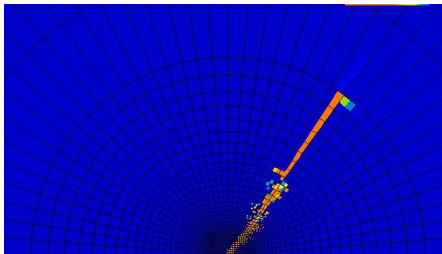
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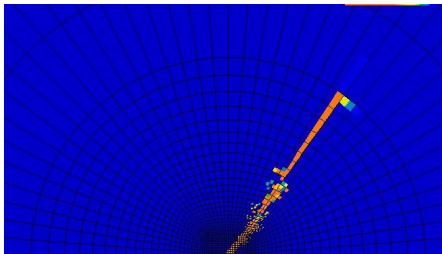
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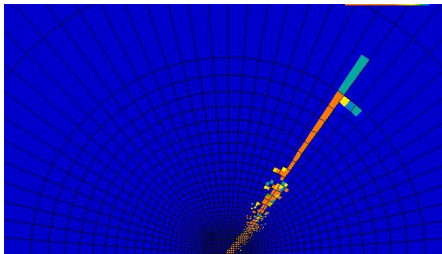
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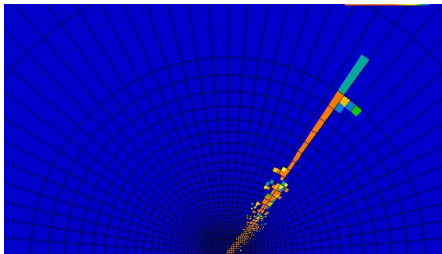
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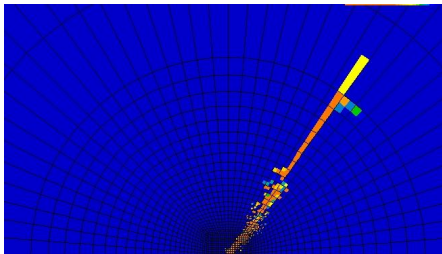
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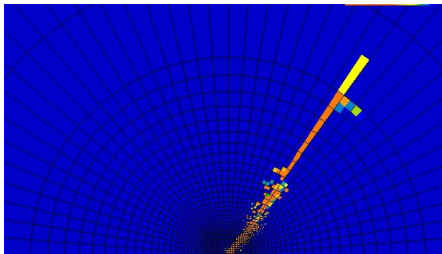
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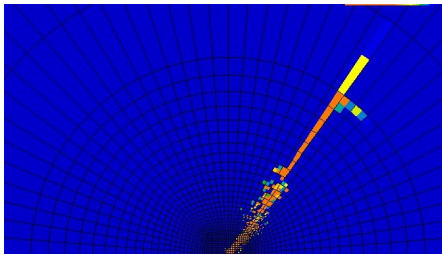
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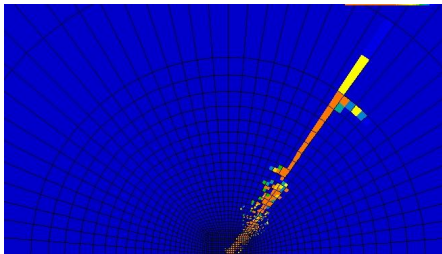
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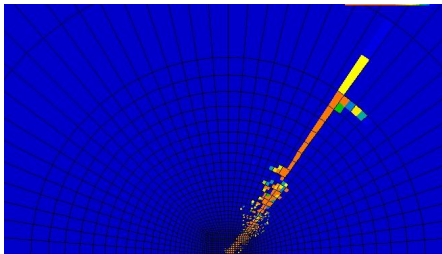
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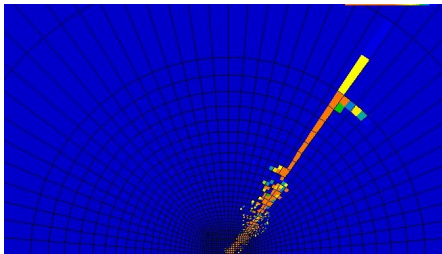
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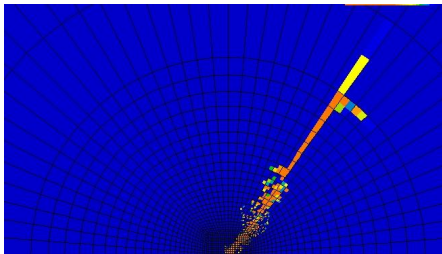
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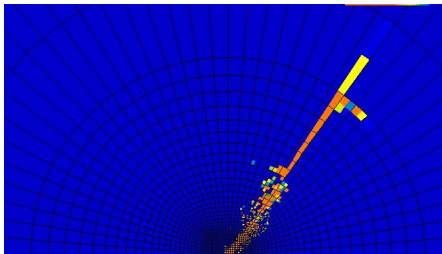
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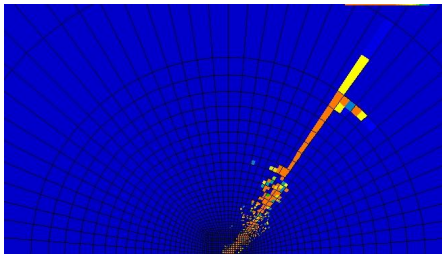
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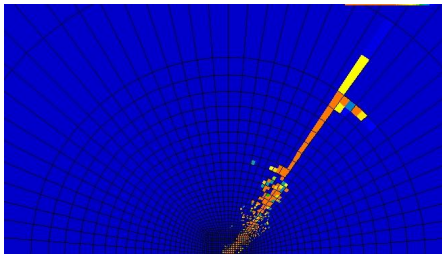
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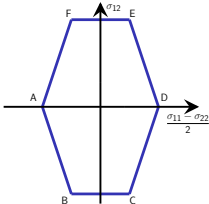
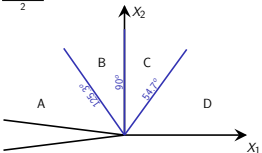
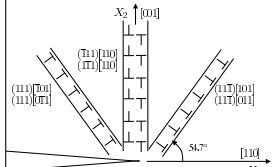
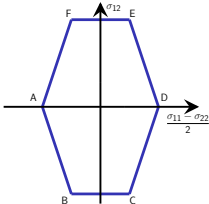
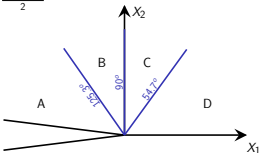
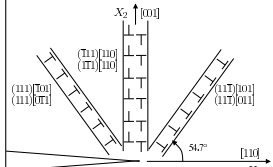


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Studied crack orientations

Name	Orientation	Surface	Discontinuity	Structure
S	$\gamma(001)[110]$			
K	$\gamma(110)[001]$			
C	$\gamma(001)[100]$	